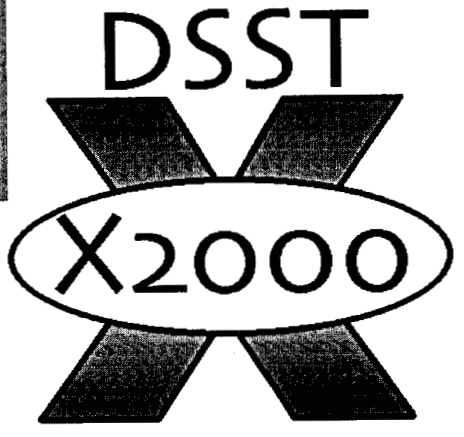
The material in this presentation is made up of things from previously cleared reports (possible with minor reformatting) and some new slides, none of which talk about new technology items.

The previously-cleared reports are:

CL 99-0064: "Extending the Computer Revolution Into Space"

CL 98-1591: "DSST Public Web Pages"



The X2000 Program

technology development
validation

Les Deutsch

Manager, Deep Space Systems Technology (DSST) Program (X2000)

Visit the DSST web site at http://www.dsst.jpl.nasa.gov

December 9, 1998

New material:

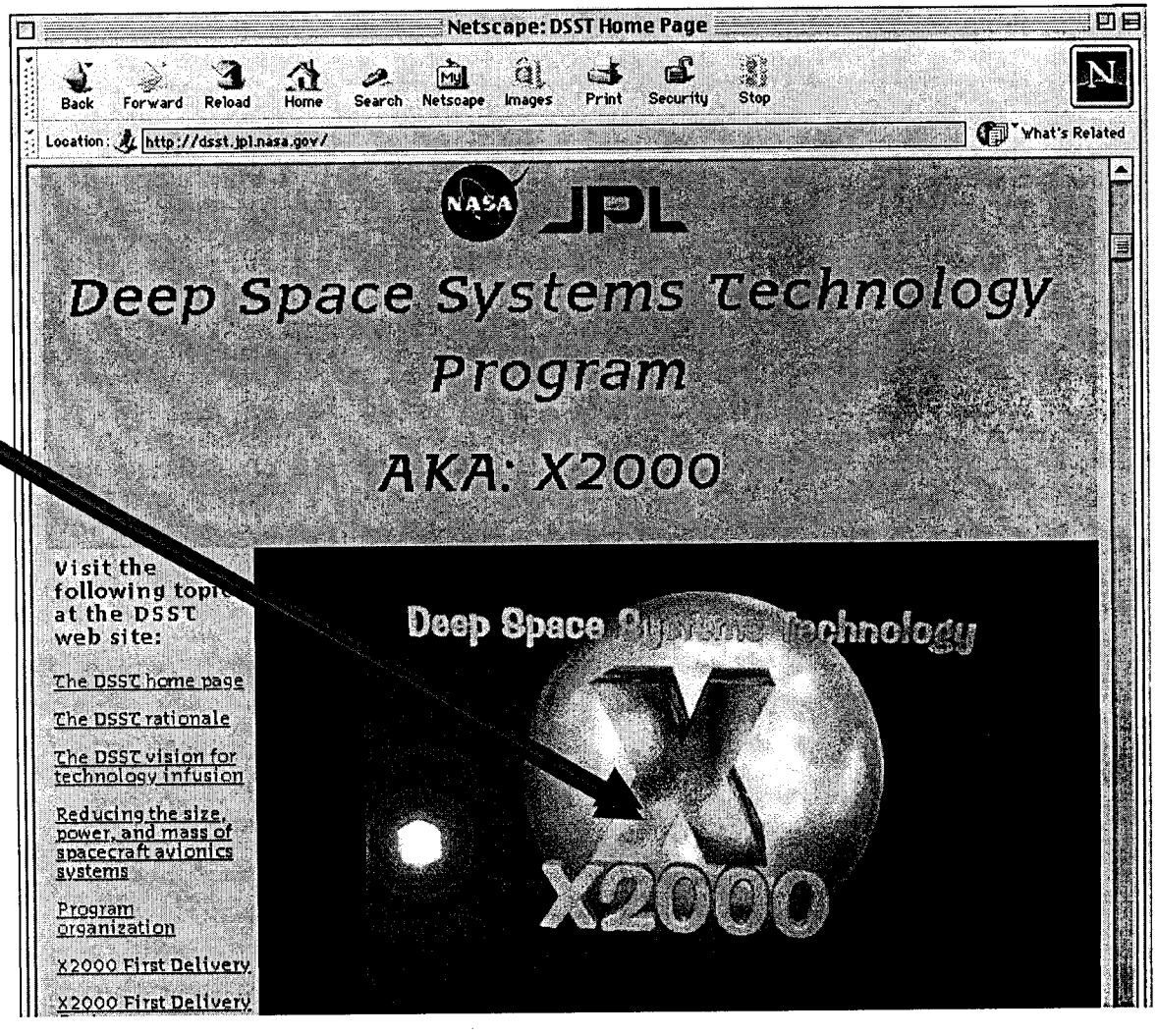
No technology

Deep Space Systems Technology Program

Introduction to X2000

The Internal DSST Web Page

- Available to registered users in the nasa.gov domain
- Go to the DSST Home Page at http://dsst.jpl.nasa.gov/
- Click on the big logo



CL 98-1591

Deep Space Systems Technology Program

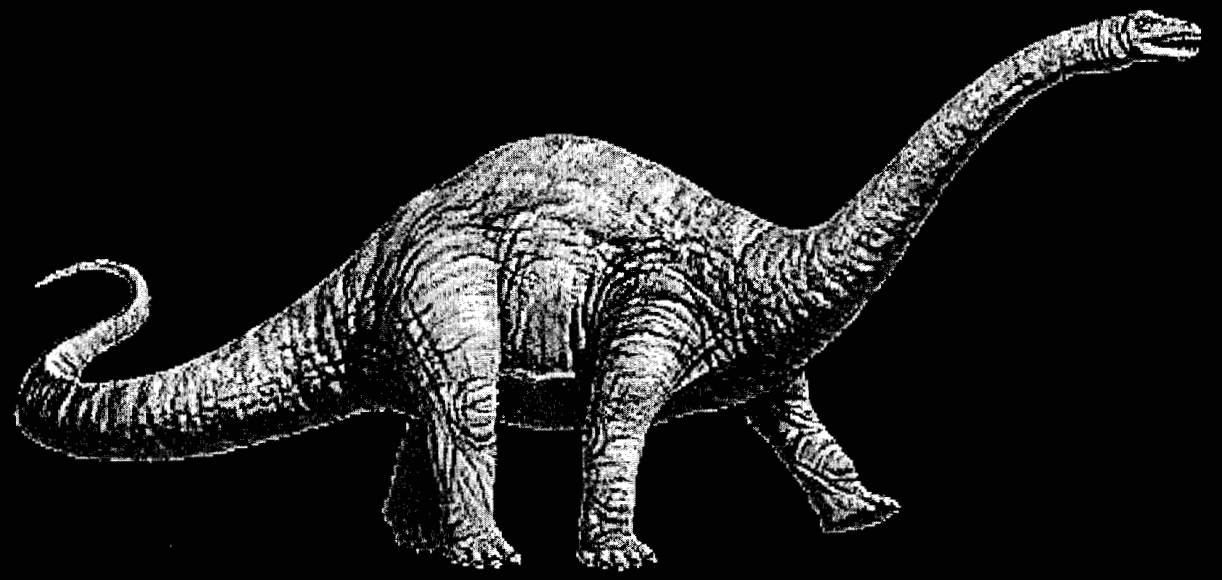
Introduction to X2000

The Old Days

DSST X2000

JPL

- Missions were large and expensive
- A new deep space mission "start" occurred only every few years
- Mission budgets were large enough to do substantial technology development
- Technology used on one mission would be obsolete by the next mission



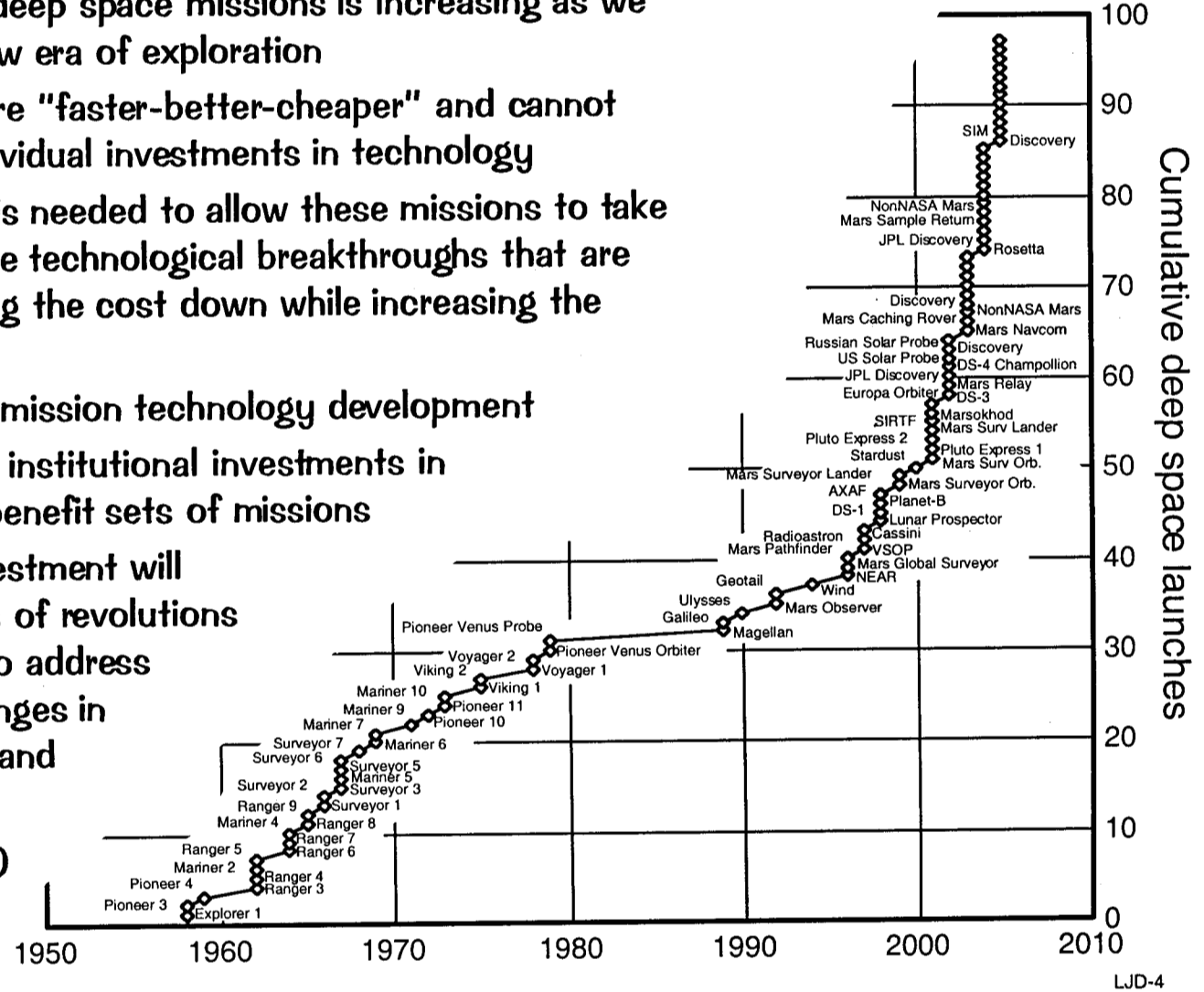
CL 99-0064

Deep Space Systems Technology Program

Introduction to X2000

The Future

- The number of deep space missions is increasing as we embark on a new era of exploration
- New missions are "faster-better-cheaper" and cannot afford large individual investments in technology
- A new process is needed to allow these missions to take advantage of the technological breakthroughs that are critical to getting the cost down while increasing the science
- The key is multimission technology development
- NASA will make institutional investments in technology to benefit sets of missions
- Continuous investment will provide a series of revolutions in technology to address common challenges in mission design and execution
- This is X2000



LJD-4
12/09/98

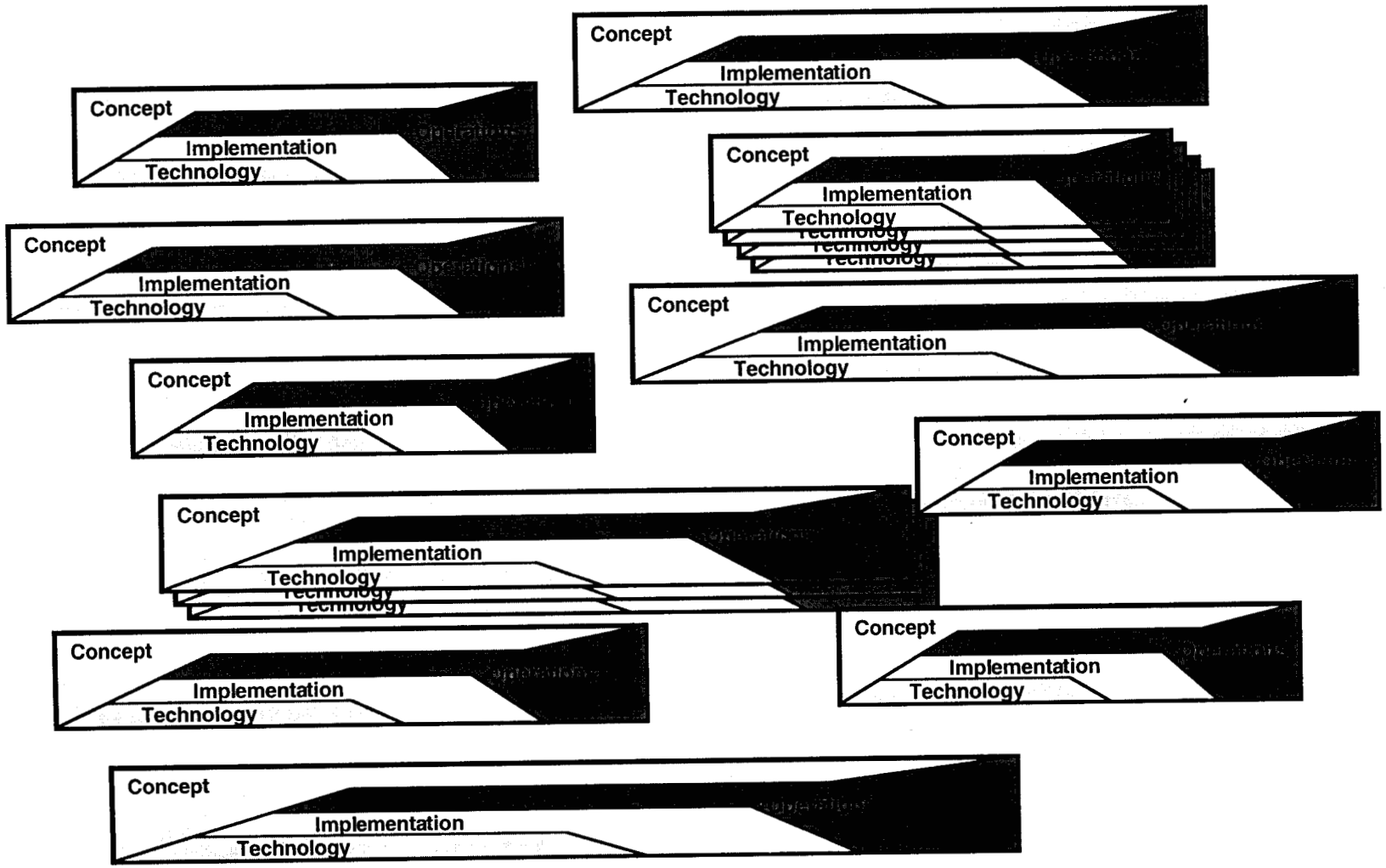
New Material -
No technology

Deep Space Systems Technology Program

Introduction to X2000

Lots of Projects

DSST X2000



New Material:

No technology

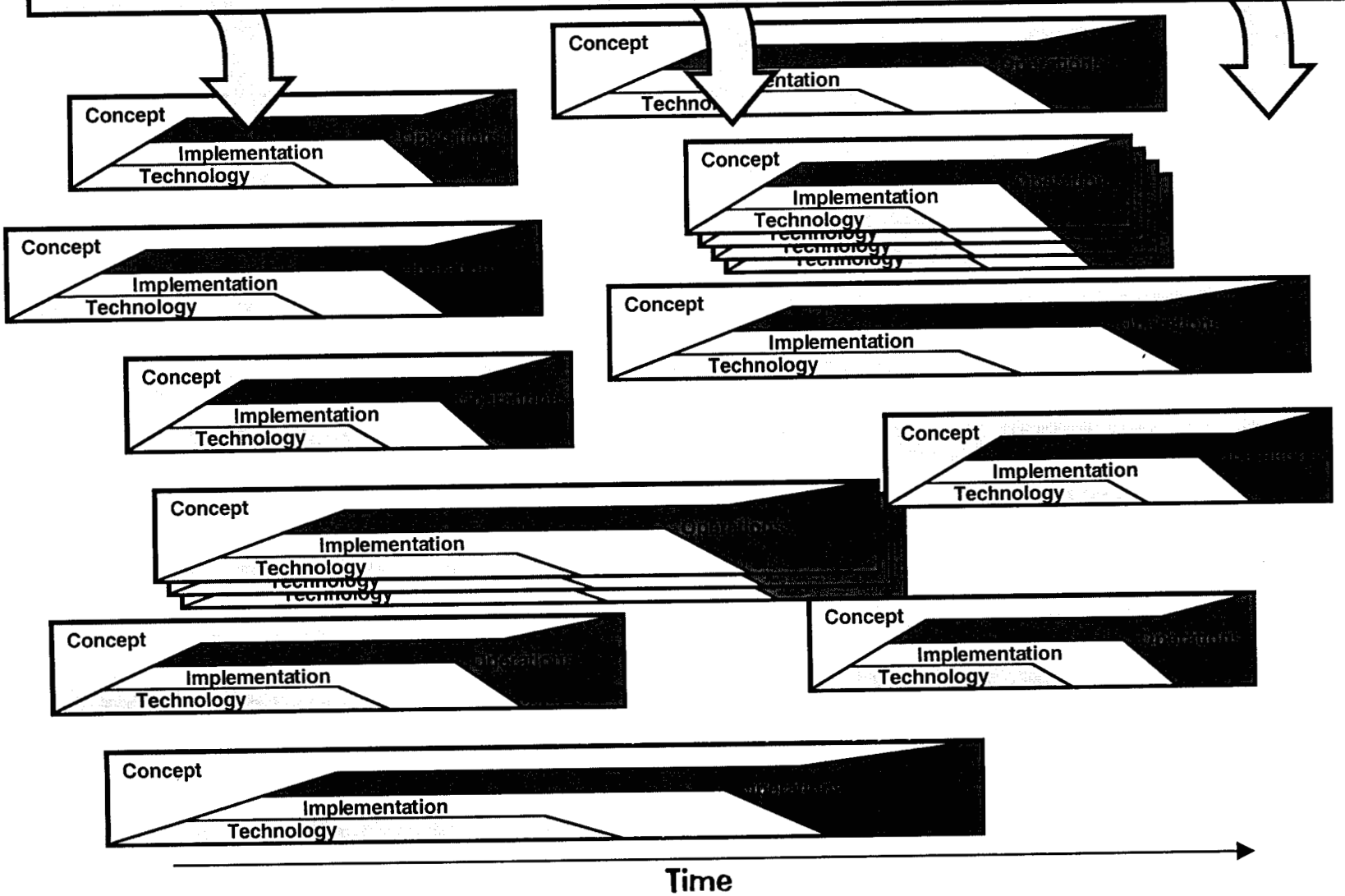
Deep Space Systems Technology Program

Introduction to X2000

Multimission Technology

DSST X2000

Multimission technology programs serve common needs of mission set



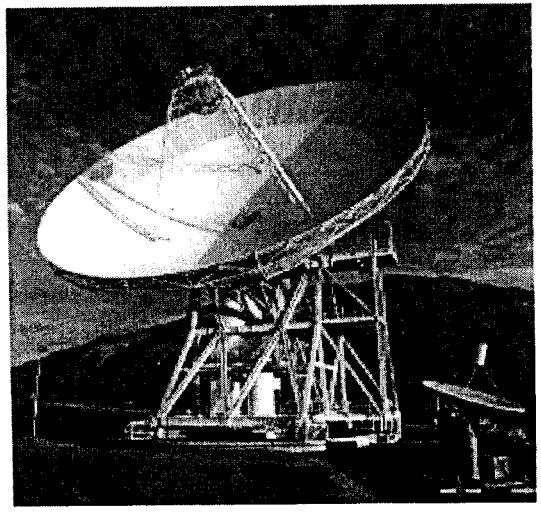
New Material:

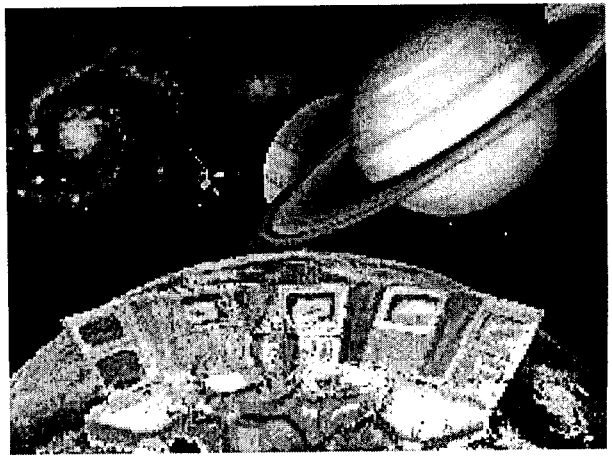
No technology

Introduction to X2000

Making Multimission Technology Work

- We already have successful multimission technology efforts in some areas
  - The Deep Space Network
  - The Advanced Multimission Operations System (AMMOS)
- These programs work because
  - There is a big market for these capabilities among flight projects
  - There is a lot of commonality in the application of these technologies
  - There is a great deal of customer (project) involvement in their development
  - The technology development in these areas is institutionally-funded
  - New capabilities are created on a schedule on which flight projects can rely





CL 99-0064

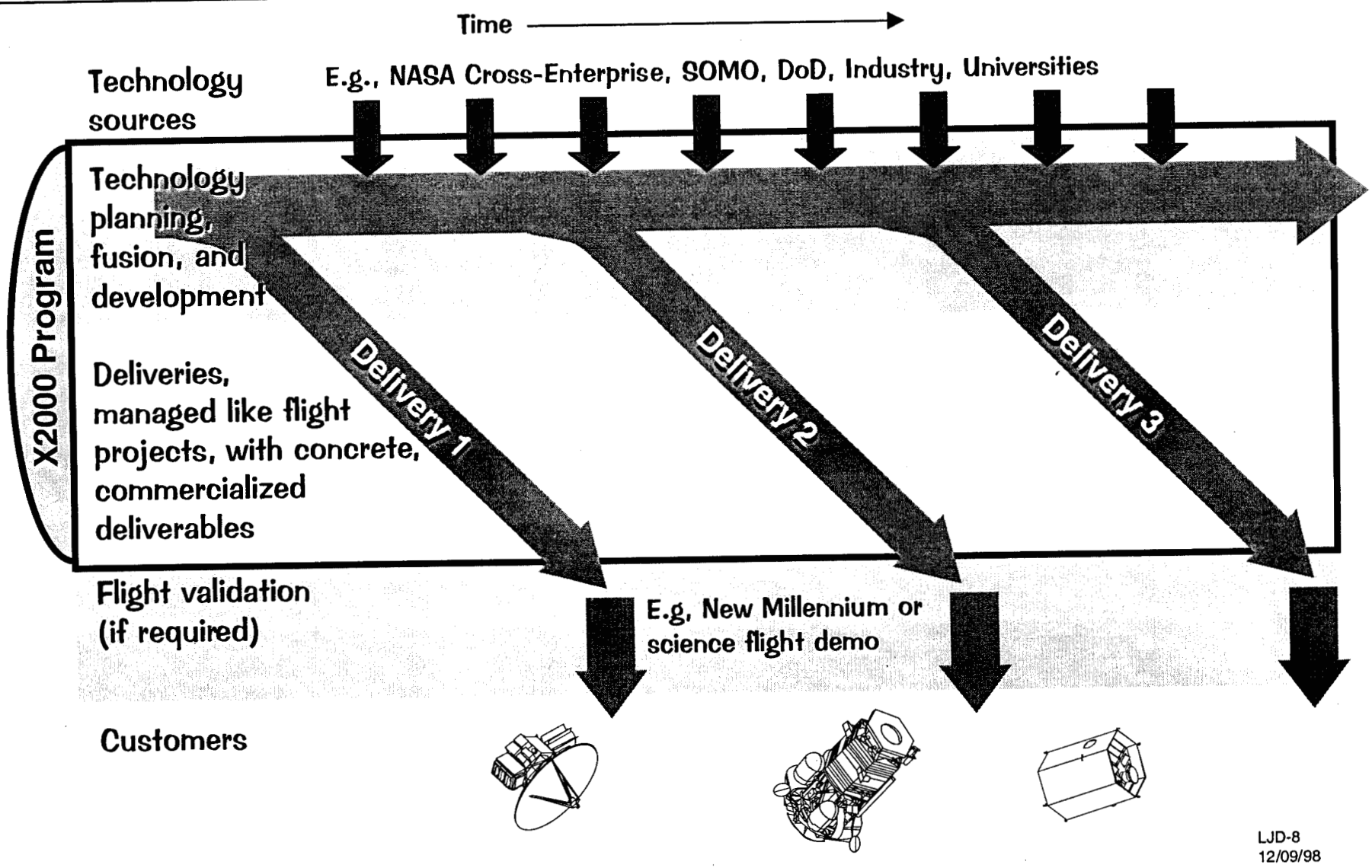
Deep Space Systems Technology Program

Introduction to X2000

X2000 Concept

JPL

DSST X2000



LJD-8
12/09/98

New Material:

No technology

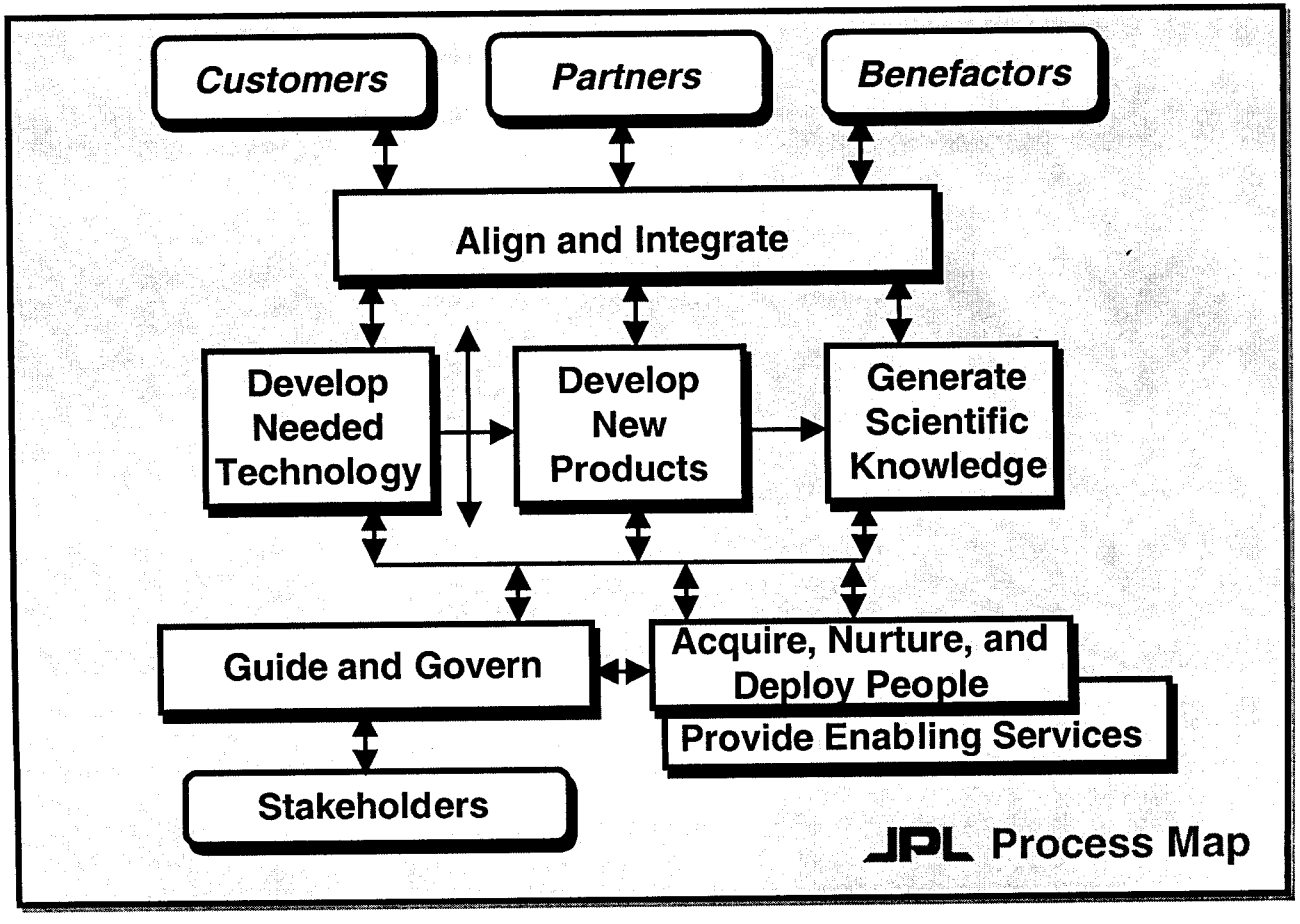
Deep Space Systems Technology Program

Introduction to X2000

What This Means for Processes

DSST X2000

- Technology development at JPL is typically managed according to the Develop Needed Technology (DNT) processes
- DSST Deliveries are managed using the Develop New Products (DNP) processes
  - DSST Deliveries are also pilots for several aspects of DNP process development



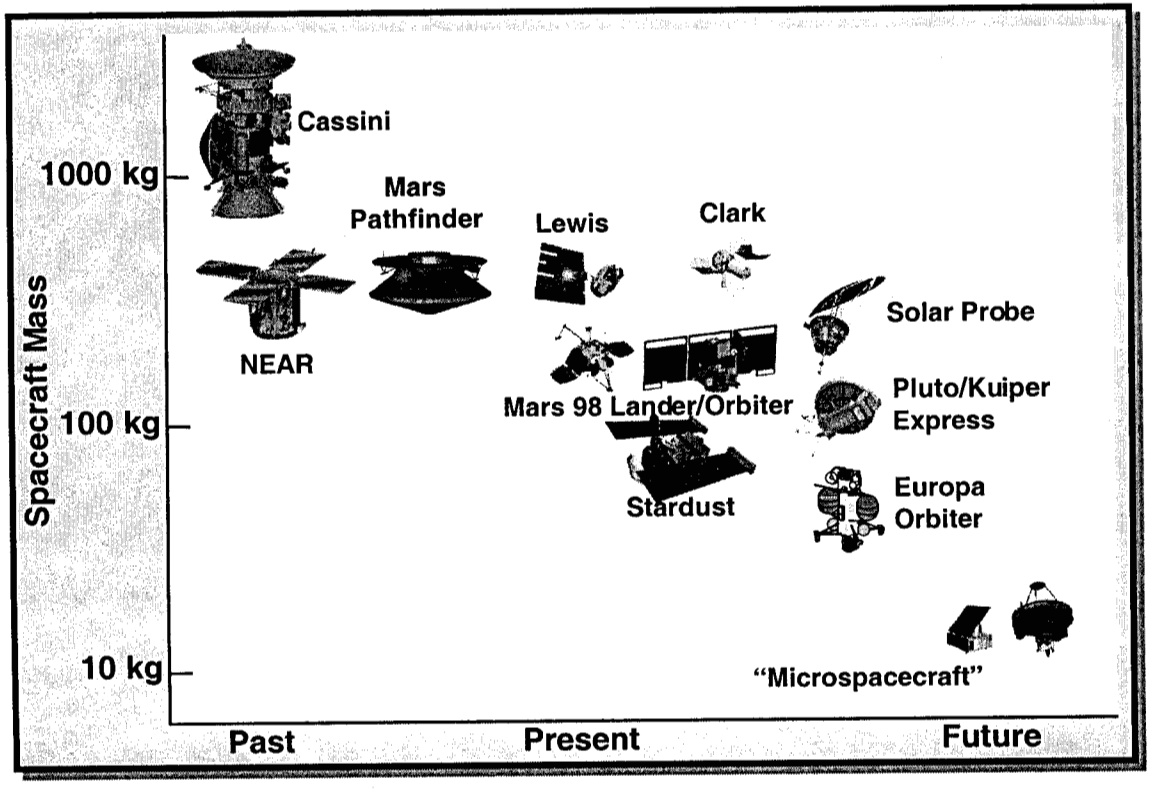
CL 99-0064

Deep Space Systems Technology Program

Introduction to X2000

Trend Toward Smaller Spacecraft

DSST X2000



X2000's Bottom Line:

- Dramatic technology breakthroughs
- Enable low-cost missions
- Science-driven architecture
- Progressive spacecraft miniaturization

CL 98-0064

Deep Space Systems Technology Program

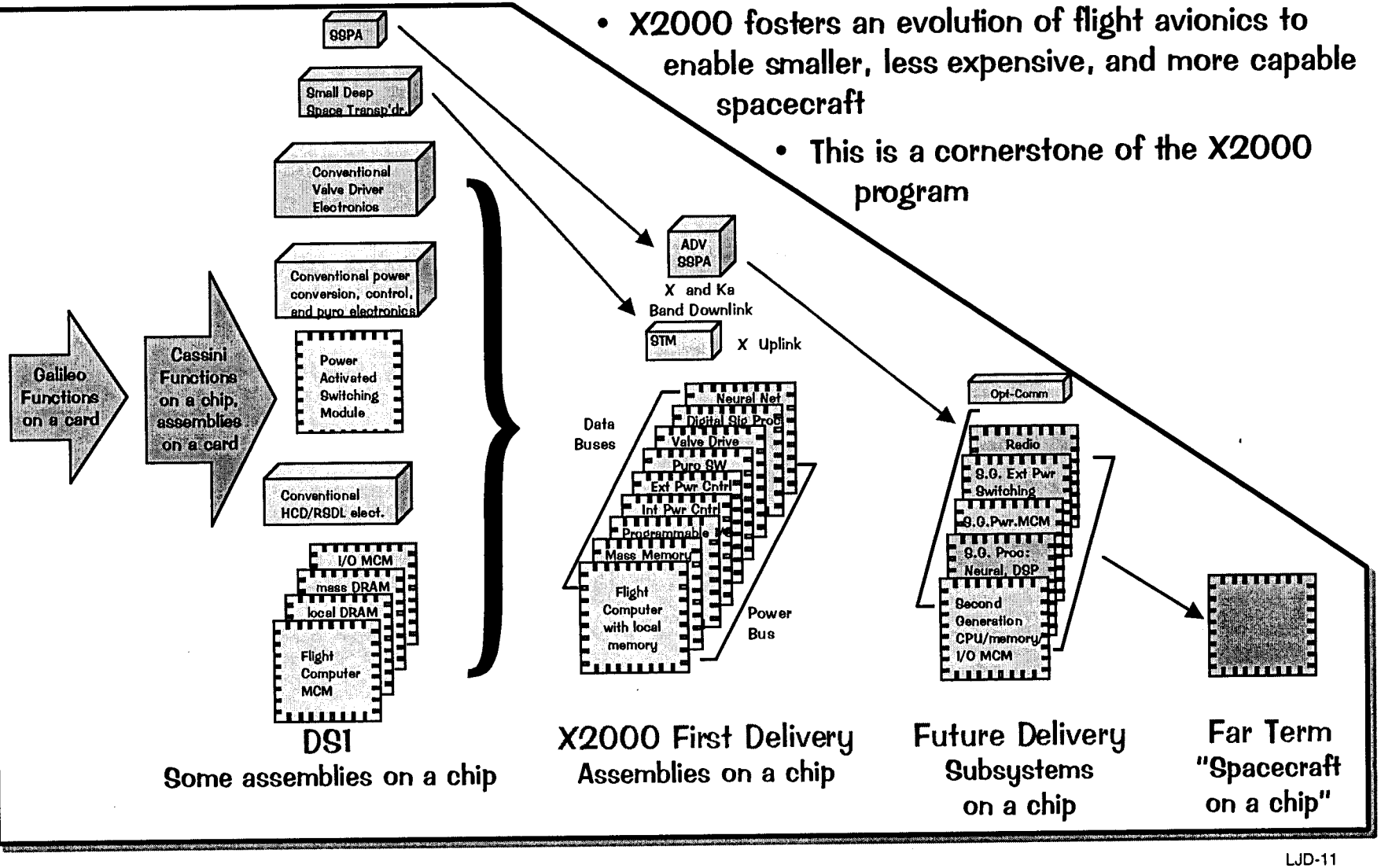
Introduction to X2000

Avionics Miniaturization

JPL

DSST X2000

- X2000 fosters an evolution of flight avionics to enable smaller, less expensive, and more capable spacecraft
  - This is a cornerstone of the X2000 program



DS1
Some assemblies on a chip

X2000 First Delivery
Assemblies on a chip

Future Delivery
Subsystems on a chip

Far Term
"Spacecraft on a chip"

New Material:

No technology

Deep Space Systems Technology Program

Introduction to X2000

Technology Portfolio

DSST X2000

X2000 is actively funding and developing technologies identified in a recent National Research Council report entitled, *"Space Technology for the Next Century"*, National Academy Press, Washington, D.C. 1998

Specifically, the report calls for:

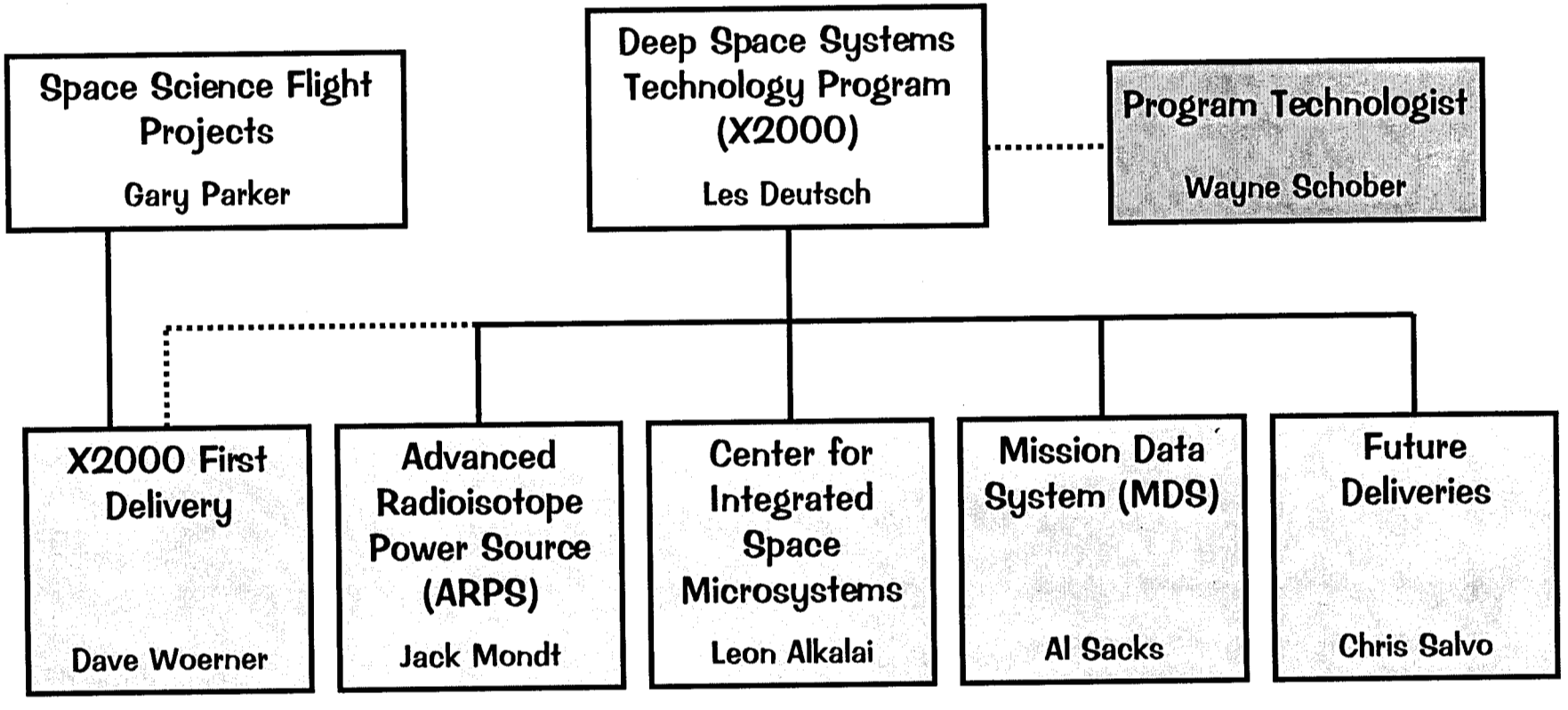
- ★ Wide-band, High Date Rate Communications Over Planetary Distances
  - ☆ X2000 is Supporting
- ★ Precisely-Controlled Space Structures
- ★ Micro-electro-Mechanical Systems (MEMS) For Space
  - ☆ X2000 is Supporting
- ★ Space Nuclear Power Systems
  - ☆ X2000 is Supporting
- ★ Low-Cost, Radiation-Resistant Memories and Electronics
  - ☆ X2000 is Supporting
- ★ Extraction and Utilization of Extraterrestrial Resources

CL 98-1591

Deep Space Systems Technology Program

Introduction to X2000

Program Top-Level Organization



- As X2000 spawns Deliveries, they become projects and are managed in like other SESPD projects
- Other program elements have commitments to deliveries as well as longer-term technology development
- The CISM element shown is programmatic, it is not the JPL Center of Excellence

Deep Space Systems Technology Program

Introduction to X2000

X2000 First Delivery

An integrated and qualified flight and ground system architecture, design, hardware, and software – specifically:

- General
  - Scalable, modular, long life
  - Radiation hardened designs, parts, & materials
  - Sensor/Instrument input and output
- Avionics
  - Computer, local memory, mass memory
  - Power & pyro switching
  - Power system control
  - Attitude control sensors
  - Packaging built into integrated avionics structure
- Communications
  - Spacecraft transponding modem (STM) with X and Ka-band capabilities
- Mechanical
  - Integrated avionics structure
  - Thermal design
- Flight and Ground software (MDS)
  - Operating systems
  - Generic auto-nav, 3-axis attitude control
  - Generic flight/ground autonomy
  - Generic flight/ground science data processing
  - Generic ground command/telemetry processing & display
- Advanced Radioisotope Power System (ARPS)
- Hydrazine micro-thruster and variable propellant regulator

CL 99-0064

Deep Space Systems Technology Program

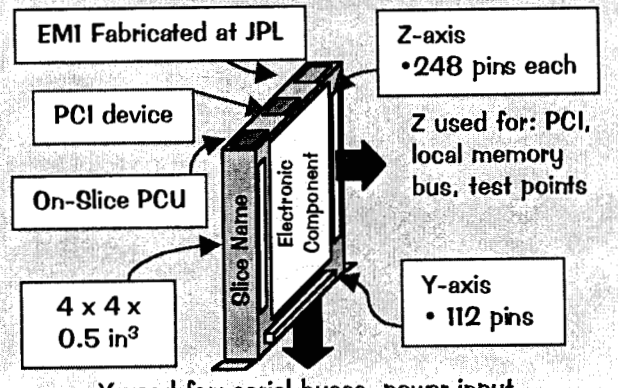
Introduction to X2000

JPL

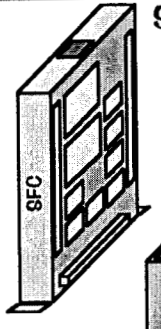
Avionics Building Blocks – 10 Slices to Mix and Match

DSST X2000

Slice Fundamentals

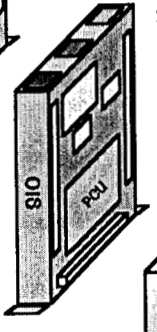


Command and Data Handling Slices

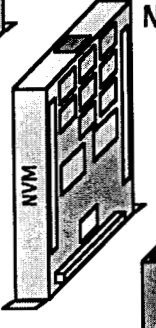


SFC - System Flight Computer
- PCI based; 128 Mbytes DRAM
- Baseline 100 MIPs

"Flight Computer" Slices

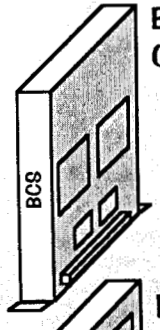


SIO - System Input/Output
- PCI/1394/I²C Bridge; Tz/ATLO I/F
- Power Saving Frequency Control

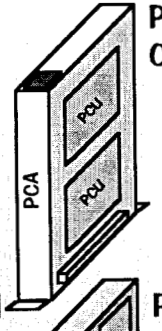


NVM - Non Volatile Memory
- 1 Gbit/slice (128 Mbyte/slice) Flash Memory
- Magnitoresistive RAM for security against radiation
- Can turn off individual NVM slices to save power

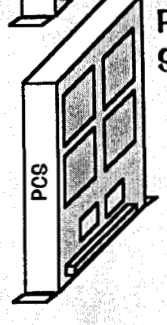
Power Subsystem Electronics Slices



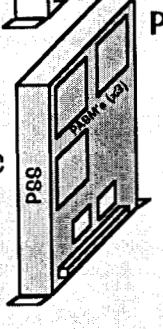
BCS - Battery Charge Slice
- Charge/discharge battery control
- Cross strapped I²C bus



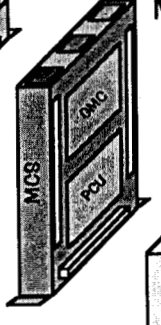
PCA - Power Converter Assembly
- Primary to secondary power conversion
- 2 power converters on 1 slice
- 10W or 30W versions
- Used to power 1394 & I²C buses



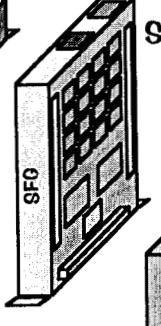
PCS - Power Control Slice
- Primary s/c power bus regulation
- Shunt regulator ASIC
- Cross strapped I²C bus



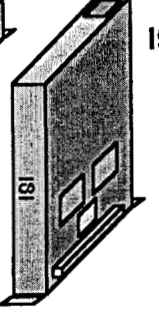
PSS - Power Switch Slice
- Switch power loads, valves & pyros
- 12 switches/slice
- Cross strapped I²C bus
- Software bypass safety inhibits for ground testing



MCS - Microcontroller Slice
- Smart interface between system buses & Power, ACS, STM & Science Instrument interfacing
- Internal PCU fanned out to "local system"
- 128 kB PROM; 512 kB SRAM; 32 kB nonvolatile



SFG - SRU Frame Grabber
- 4 Mb RAM min (16 MB target)
- PCI interface to MCS and serial interface to SRU



ISI - IMU/SSA Interface
- SSA sensor conditioning
- serial interface IMU

CL 99-0064

Deep Space Systems Technology Program

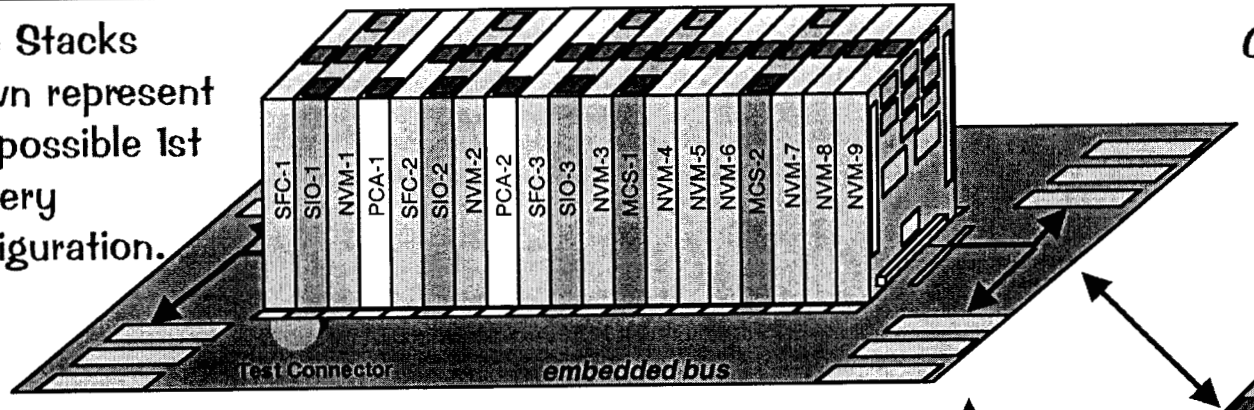
Introduction to X2000

System Construction

JPL

DSST X2000

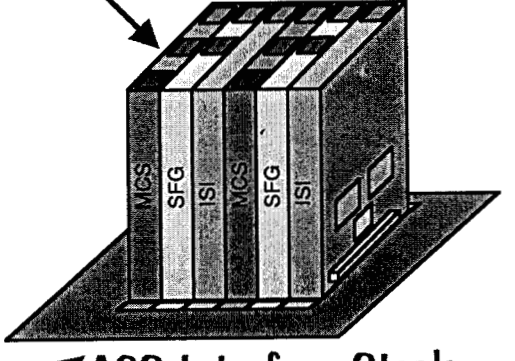
Slice Stacks shown represent one possible 1st delivery configuration.



CDH Stack

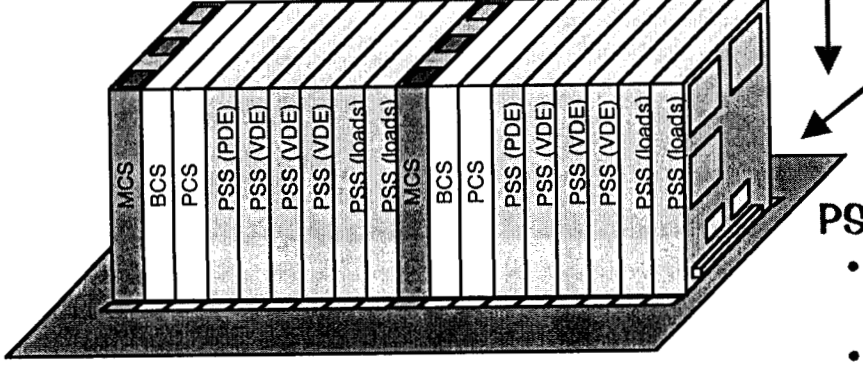
- *3 computers*
- *Global NVM*
- *Test & launch vehicle access*

1. Design embedded network bus using slice CAD models
2. Allow for test and traditional connector access
3. Populate with slices
4. Test!
5. Continue with System Integration



ACS Interface Stack

- Block redundant
- Each half interfaces to one of 3 attitude determination sensors



PSE Stack

- Twin Microcontrollers (MCS) plus cross strapped I^2C subsystem bus
- Slice compliment based on EM1

LJD-16
12/09/98

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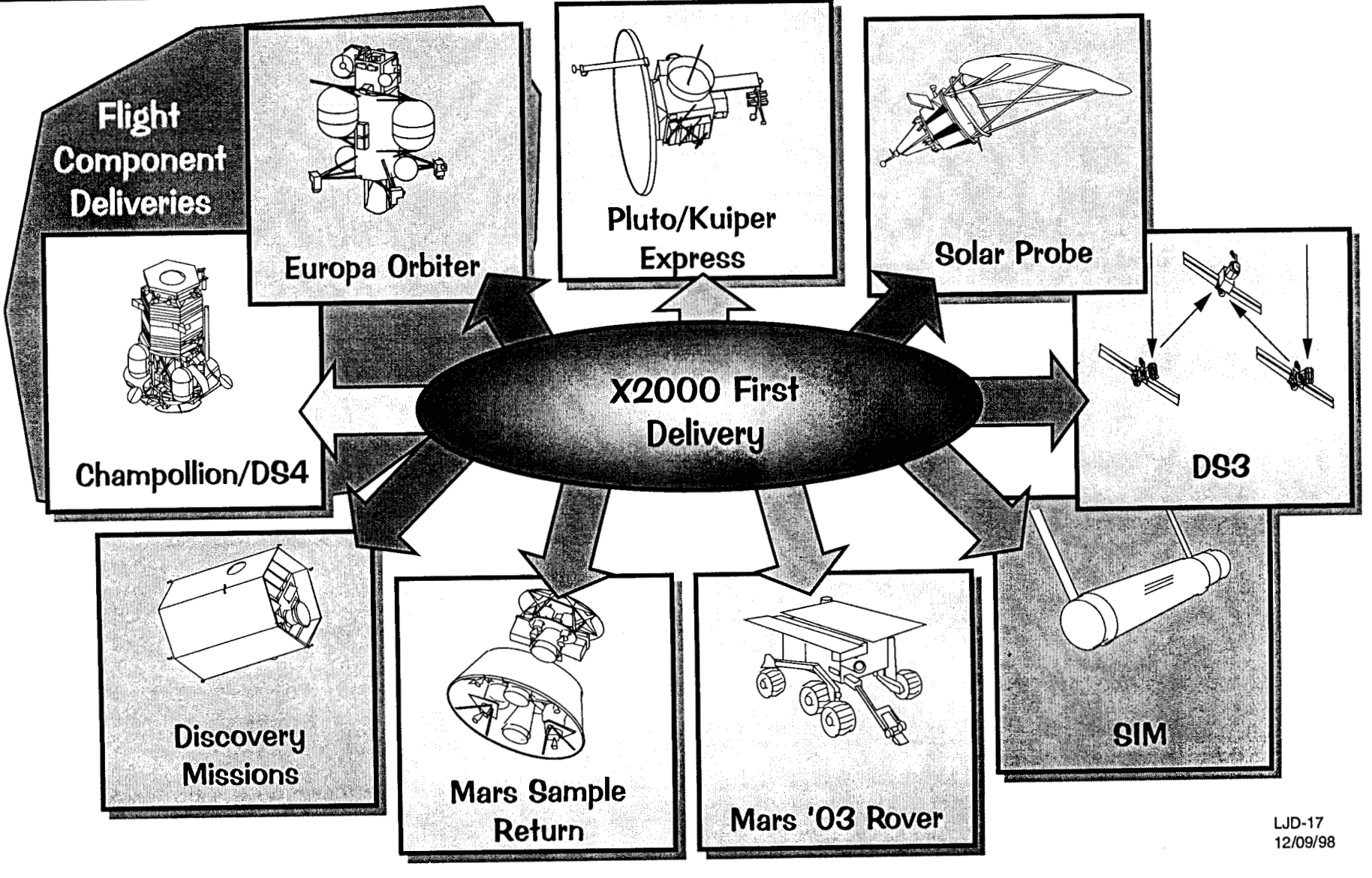
Deep Space Systems Technology Program

Introduction to X2000

Customers for X2000 First Delivery

JPL

DSST X2000



LJD-17
12/09/98

CL 99-0064

Deep Space Systems Technology Program

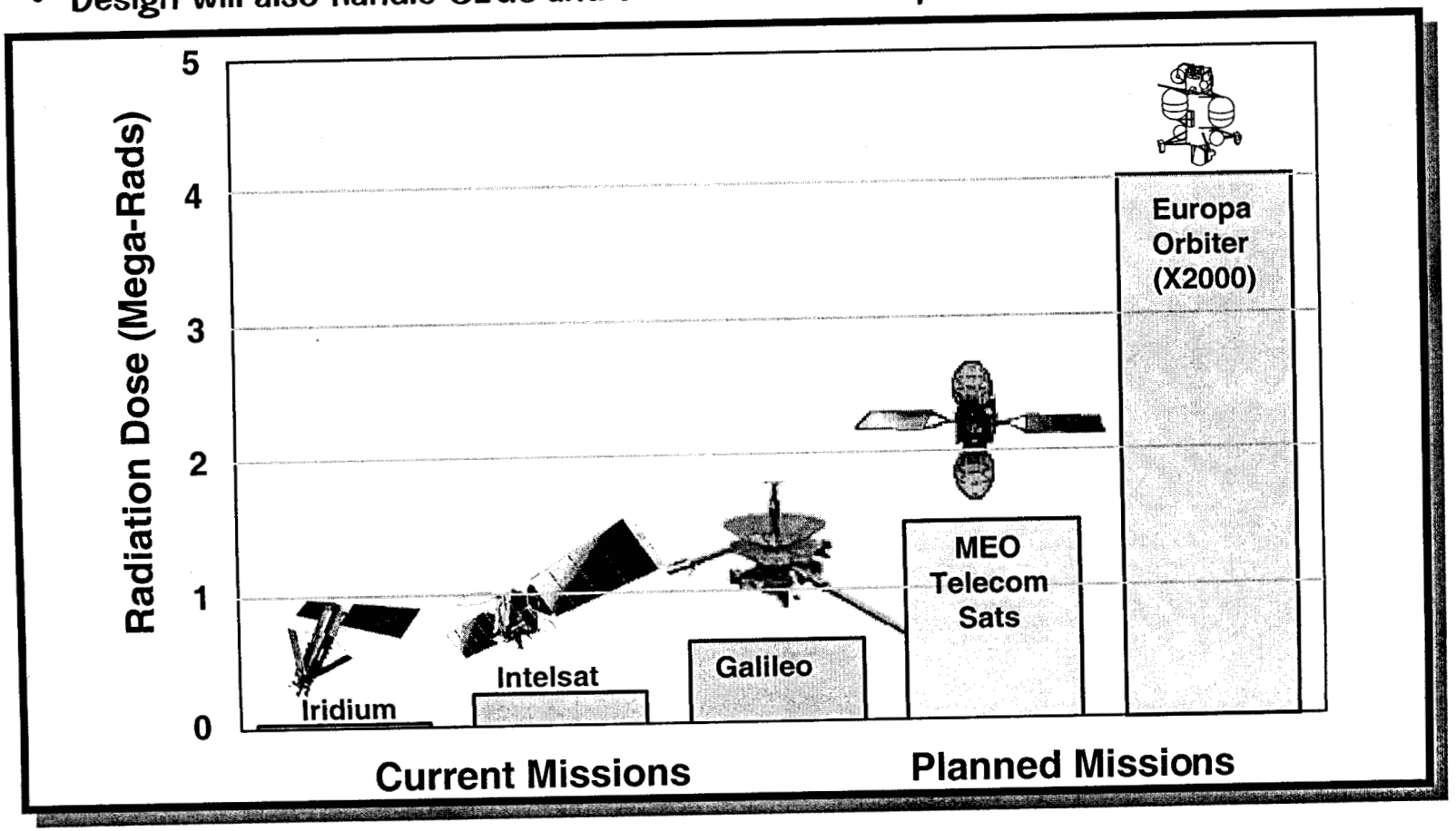
Introduction to X2000

Radiation-hard Delivery

JPL

DSST X2000

- X2000 First Delivery will deliver radiation-hard capabilities
- Designs and components will also be useful for commercial endeavors
- Design can handily survive in LEO, GEO, and deep space, and enables MEO missions
- Design will also handle SEUs and will be immune to particle-induced latch-up



LJD-18
12/09/98

New Material:

No technology

DSST X2000

X2000 First Delivery provides many benefits to the nation and U.S. Space Program:

- Lower recurring cost for components will enable execution of the next generation of low-cost missions while preserving reliability and boosting radiation hardness well beyond Galileo and Cassini
- A flight and ground software system architecture will produce the first fully integrated Mission Data System
- Designs and components will be produced that will be useful for commercial endeavors and spin-offs – and can survive radiation in LEO, GEO, and deep space, and enable long-life MEO missions
- The Advanced Radioisotope Power System will dramatically lower the amount of Pu238 required to fly deep space missions
- Low power and low mass systems

New Material:

No technology

Deep Space Systems Technology Program

Introduction to X2000

First Delivery Benefits

DSST X2000

Tangible benefits:

- Proven equipment and designs
- Rad-hard designs
- Low recurring cost
- Low power consumption
- Low mass
- Long-life equipment
- Flight system to PC connectivity
- Centralized, on-line documentation of designs
- Reduces Pu238 for power system
- Integrated Mission Data System
- New propulsion technology for smaller lighter spacecraft
- New communications technology for smaller lighter, lower power spacecraft
- Integrated electronics and structure

Further benefits:

- Risk reduction
- Mission enabling
- Upgradability
- End-to-end services and maintenance
- Faster National Environmental Protection Agency (NEPA) and Launch Approval for missions using ARPS
- Improved potential for commercial spin-offs and endeavors
- Shorter mission development times for follow-on missions
- Enhances U.S. spacecraft and component developers technology base
- Develops major space technology program for the next century

CL 98-1591

Deep Space Systems Technology Program

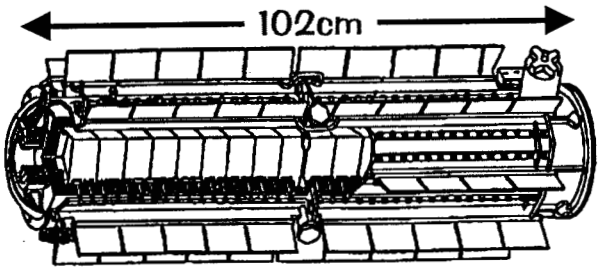
Introduction to X2000

Advanced Radioisotope Power System (ARPS)

DSST X2000

- X2000 is developing, in partnership with DoE, an advanced, highly efficient radioisotope power system that dramatically reduces the use of radioactive material for U.S. space missions – will be part of X2000 First Delivery

Today:

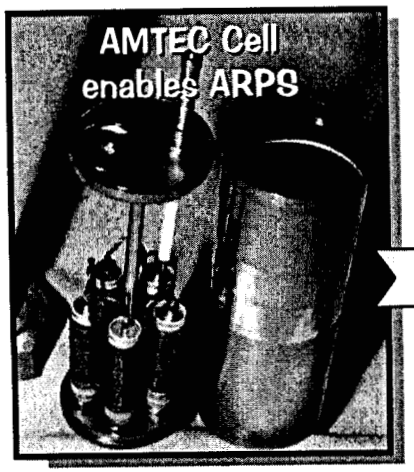


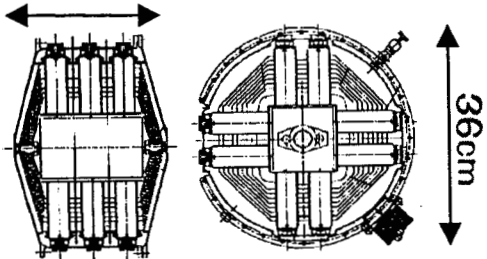
One of three Cassini Radioisotope Thermoelectric Generators (RTGs)

CASSINI RTGs:
Power = 855 watts
Mass = 168 kg
PuO_2 Mass = 32.4 kg
Pu^{238} Mass = 23.4 kg

X2000/ARPS

Future:





One ARPS per Outer Planets/Solar Probe missions

OP/SP ARPS:
Power =150 watts
Mass = 16 kg
PuO_2 Mass = 3.0 kg
Pu^{238} Mass = 2.2 kg

LOCKHEED MARTIN

LJD-21
12/09/98

New Material:

No technology

Introduction to X2000

Advantages to the ARPS

- Does not change the design of existing Plutonium fuel "bricks"
  - Avoids cost of developing new Plutonium containment system and passing certification
- Increased conversion efficiency could mean easier launch approval for some missions
- Potential for very small, low power applications using single bricks

CL 98-1591

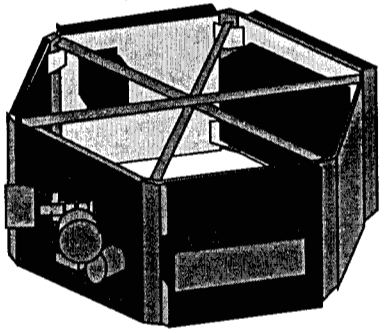
Deep Space Systems Technology Program

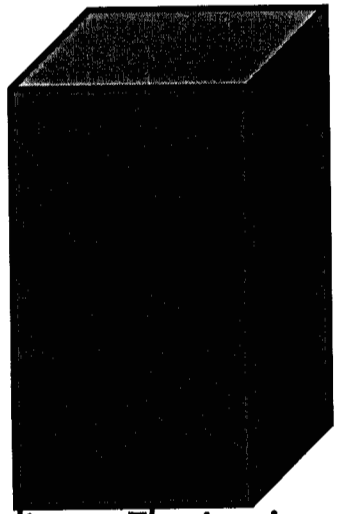
Introduction to X2000

Center for Integrated Space Microsystems (CISM)

JPL

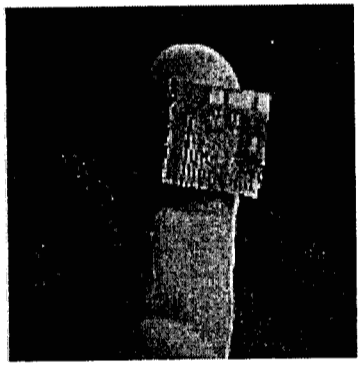
DSST X2000

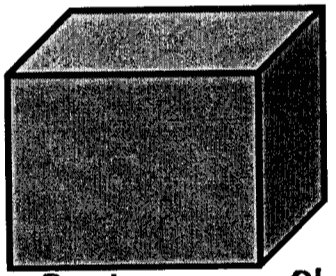




1st Delivery Electronics

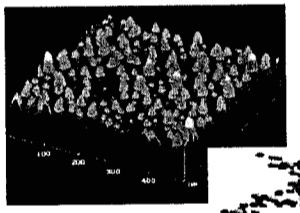
- Power electronics
- Telecom processing
- 3D multichip module standard
- Integrated architecture





Avionics System-on-a-Chip

- Begin design and fabrication of minimum avionics system-on-a-chip.
- Telecom, power management, CPU, memory, and sensors.



Revolutionary Computing

- Reconfigurable computing
- Ultra-low-power electronics
- Quantum computing
- MEMS-Optics, etc.

LJD-23
12/09/98

CL 99-0064

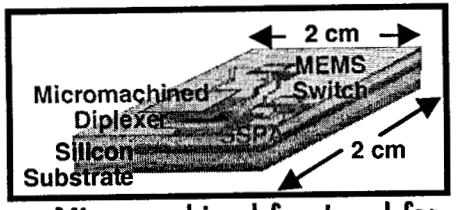
Deep Space Systems Technology Program

Introduction to X2000

CISM: System on a Chip (SOAC)

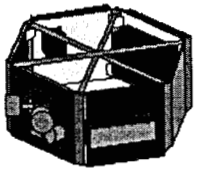
DSST X2000

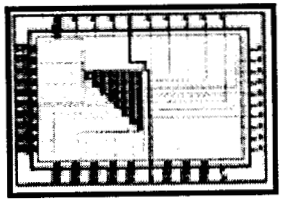
JPL



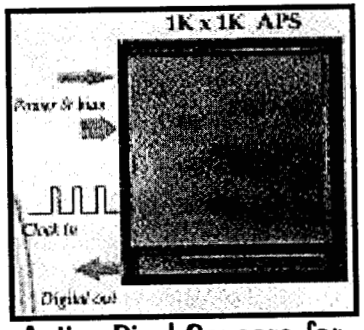
Micromachined front end for miniaturized RF comm system

X2000 First Delivery:
~10,000cc, ~60 kg, ~150W

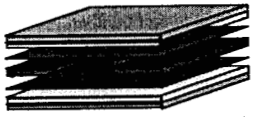




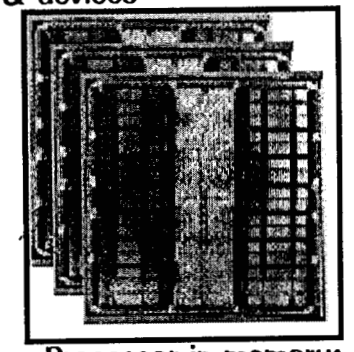
Ultra-low-power architecture & devices



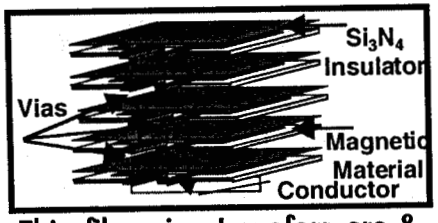
Active Pixel Sensors for low-power optical comm. & advanced star trackers



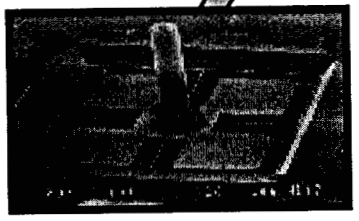
SOAC:
<100cc, <1 kg, ~ 30 -50W



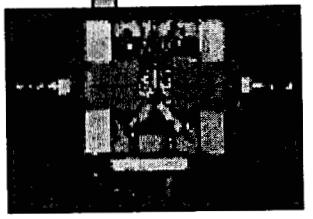
Processor in memory:
Multiple CPU/chip with DRAM, SRAM, NVRAM, BIST, fault Tolerance



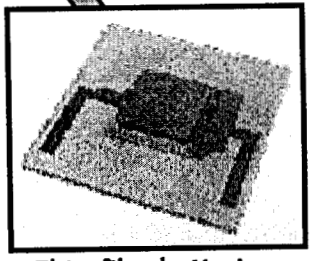
Thin film microtransformers & passive components for miniaturized power management and distribution



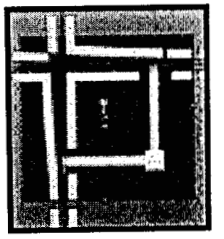
Micromechanical inertial reference system for mini guidance & nav



Thermoelectric thin film coolers for advanced thermal control



Thin film batteries for on-chip power storage



High bandwidth, low power, optoelectronic switch for high speed optical bus

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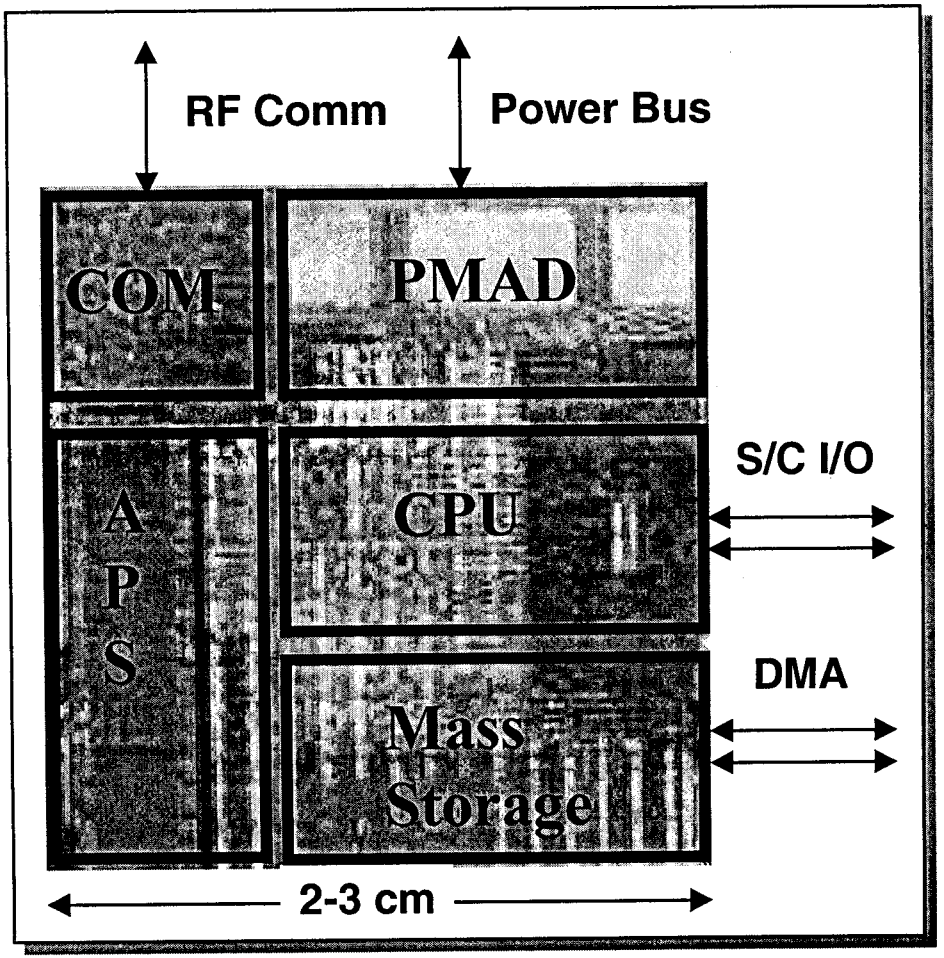
12/09/98

Introduction to X2000

CISM: System-on-a-Chip (SOAC) Vision

- Definition:
  - Highly capable, autonomous avionics system which includes CPU, mass memory, power management and distribution, telecomm, and sensors; all integrated into a single monolithic unit.
- Benefits:
  - Volume/Mass reduction
  - Improved performance and reliability
  - Power reduction
- Applications:
  - Spacecraft
    - Micro Spacecraft
    - Science Craft
    - Micro Probe
  - Micro and Nano Rovers
  - Aerobots



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Deep Space Systems Technology Program

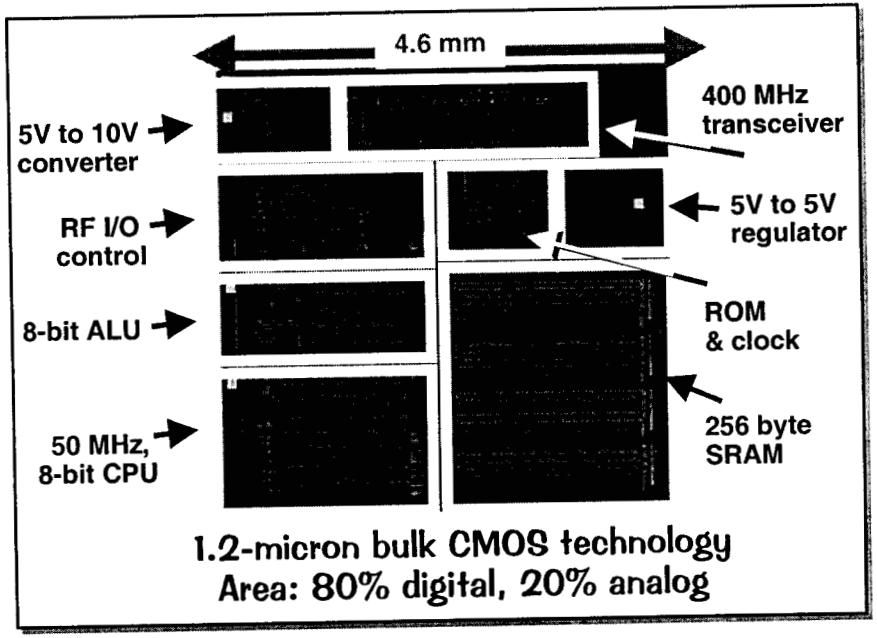
Introduction to X2000

First Generation Integrated Chip

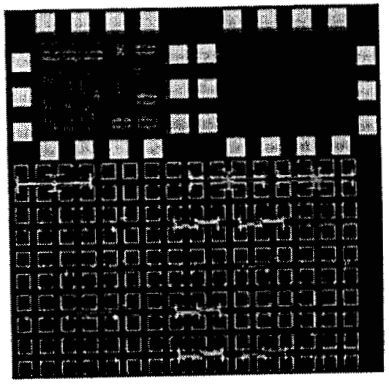
JPL

DSST X2000

- Work performed in collaboration with the University of Illinois, Chicago
- The first generation integrated chip was selected for DARPA run at MIT Lincoln Lab.
- Designed entire chip in < 7 weeks (generated own libraries)
- Implemented a variety of designs with varying degrees of functionality to ensure we understand the process and are able to assess limitations for future developments
- Designed "test chip" with variety of test structures – important to understand Silicon-On-Insulator (SOI) CMOS process and capability
- This effort helped to highlight challenges of existing design tools and provide valuable lessons learned
- Chips will be ready for testing in January



1.2-micron bulk CMOS technology
Area: 80% digital, 20% analog



Test chip

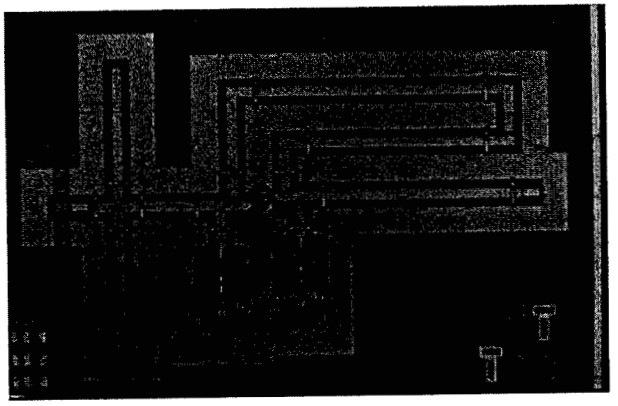
UIC

Deep Space Systems Technology Program

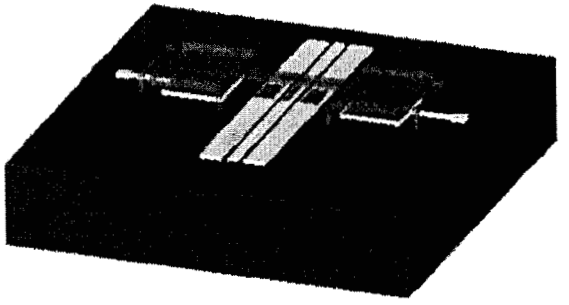
Introduction to X2000

RF Front End

- Work performed in collaboration with the University of Michigan
- Completed simulations of two types of switches:
  - A compliant switch for low activation voltage and high power handling capability
  - A switch pair for high isolation
- Fabricated a high isolation switch prototype
- Developed new fabrication process for filters
- Designed the high power multifinger SiGe HBT



SiGe 3-stage amplifier



RF switch

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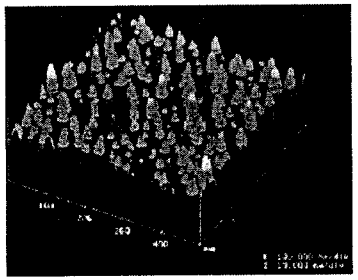
Deep Space Systems Technology Program

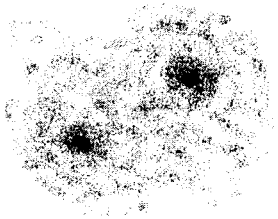
Introduction to X2000

CISM: Revolutionary Computing Technologies

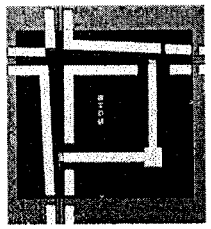
DSST X2000



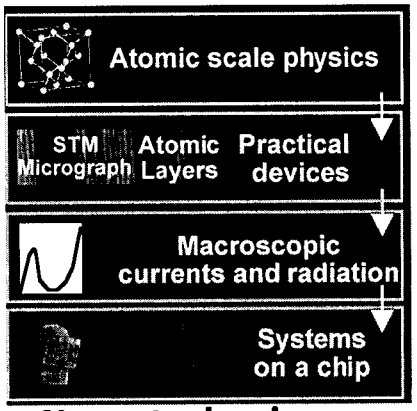
Quantum Dots



Quantum Computing



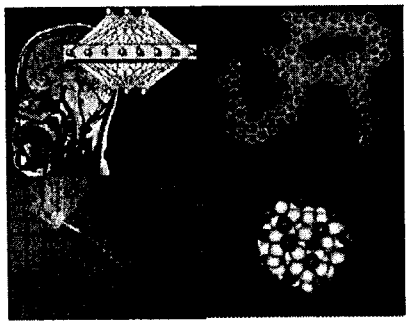
Optical Computing



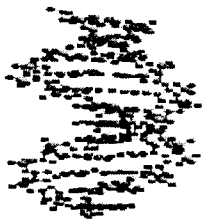
Nano-technology Modeling

"Mission - inspiring"

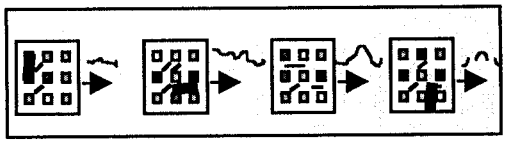
Breakthrough Revolutionary Computing Technologies & Architectures



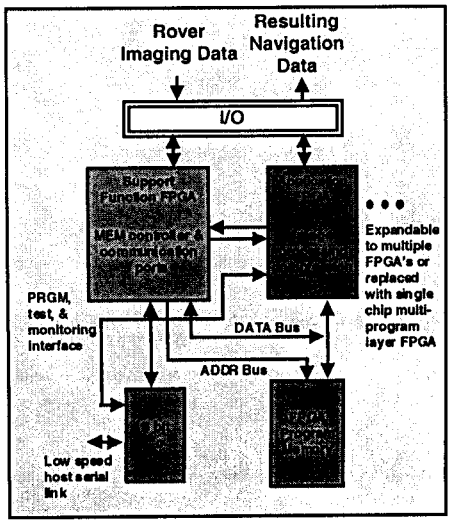
Biological Computing



DNA Computing



Evolvable Hardware



Reconfigurable Computing

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New Material:

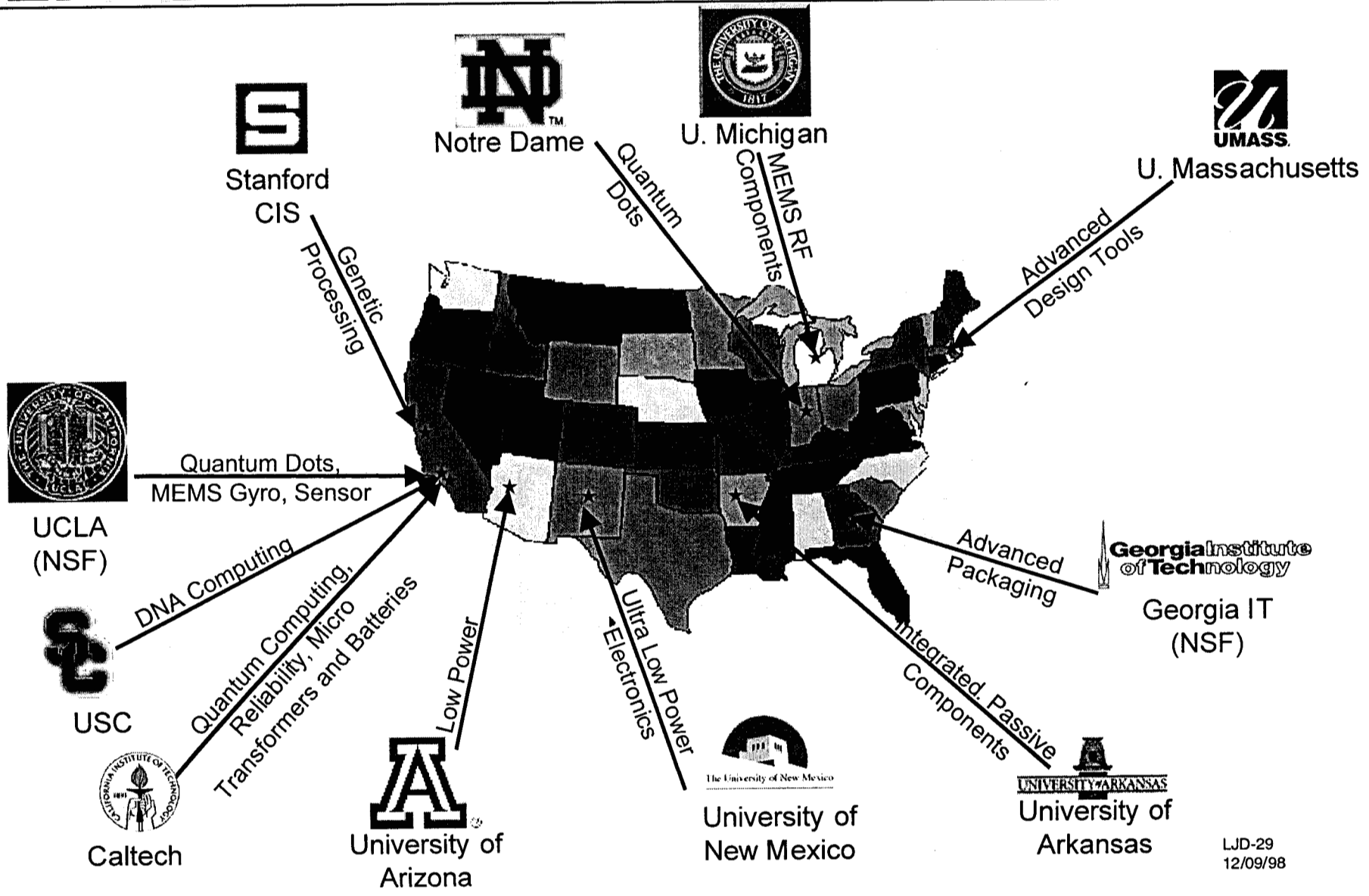
No technology

Deep Space Systems Technology Program

Introduction to X2000

CISM University Partners

DSST X2000



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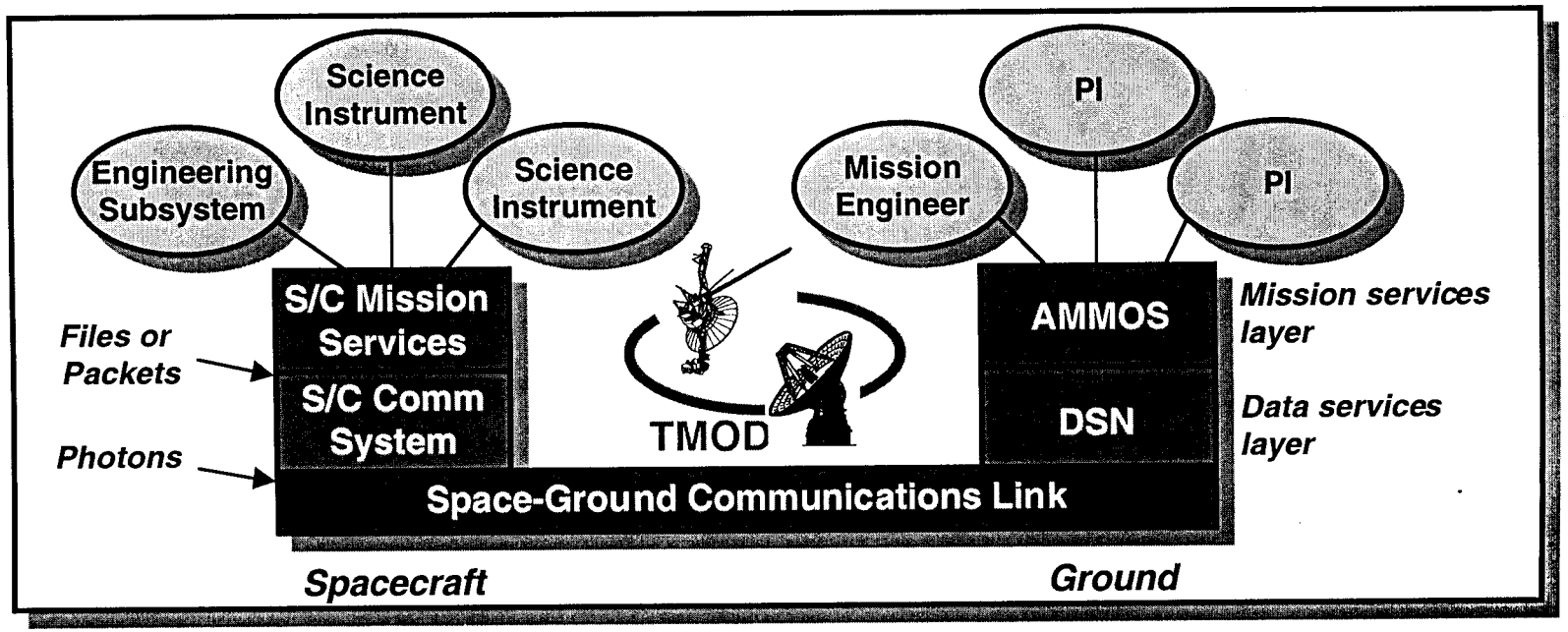
Deep Space Systems Technology Program

Introduction to X2000

Mission Data System (MDS)

- The MDS is the glue that holds all the components of X2000 together
  - Includes all flight and ground software required to provide delivered functionality
  - Embodies the end-to-end system architecture
- Effort is led by JPL's Telecommunications & Mission Operations Directorate (TMOD)
  - TMOD provides operations services to missions
  - MDS will integrate traditional mission specific software with multimission aspects including the Deep Space Network (DSN)
- MDS effort has a continuous evolution as will as capabilities in individual deliveries
- **MDS will define the way all future JPL missions are operated**



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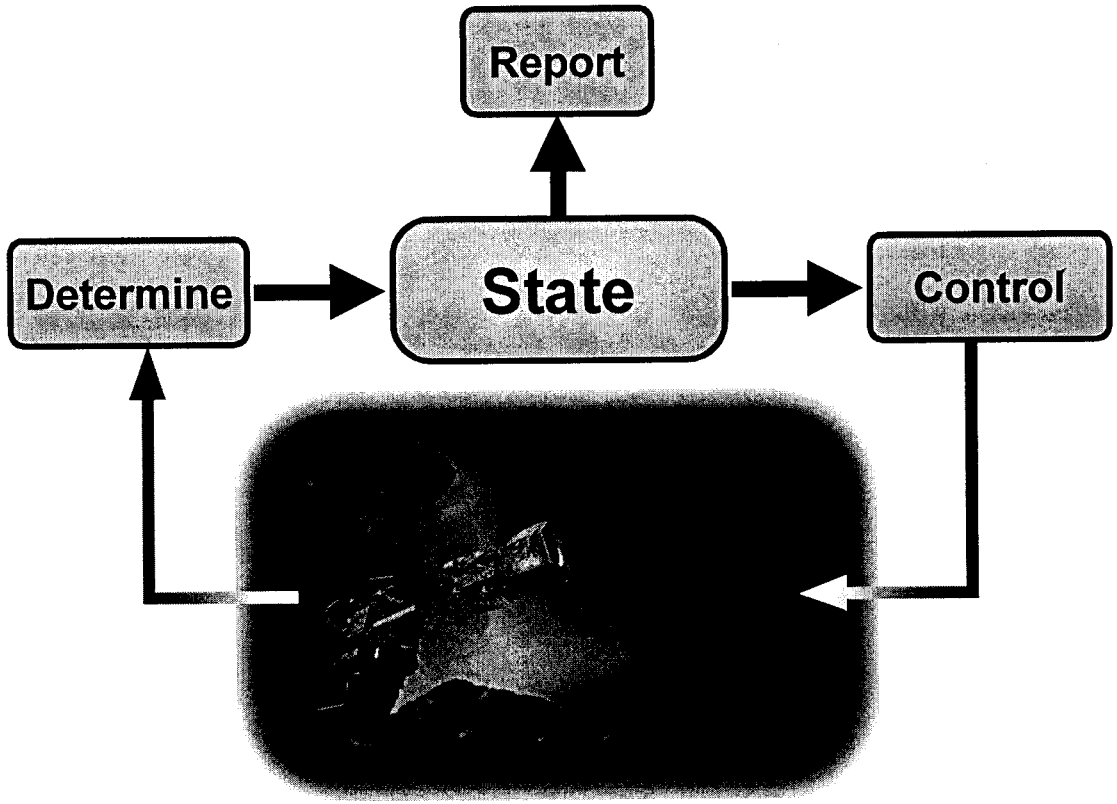
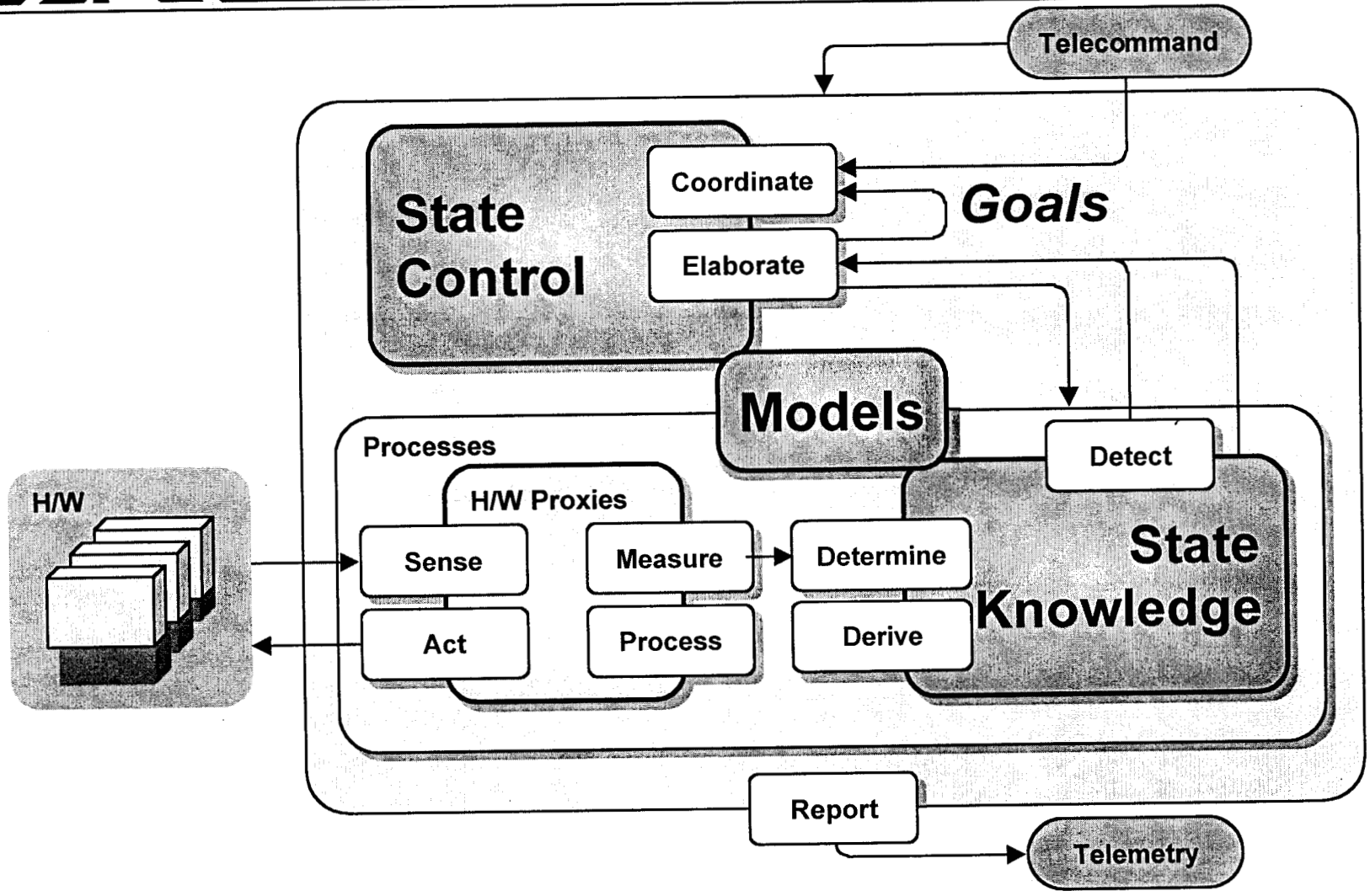
- "State" is the central concept to the MDS
- Spacecraft and ground states are managed rather than individual low-level controls



Introduction to X2000

MDS Goal-Oriented Automation



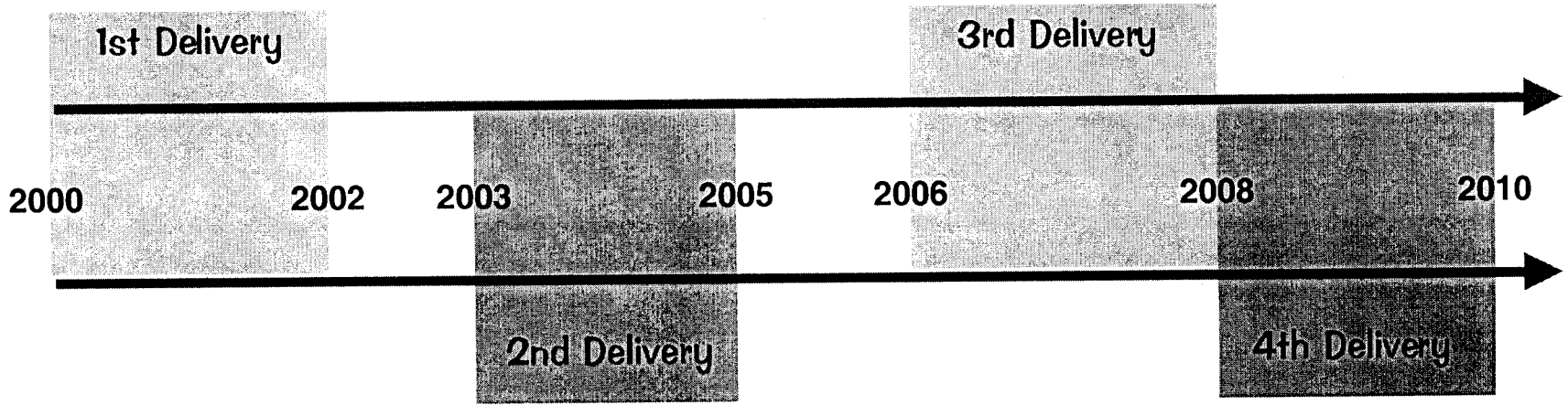
Introduction to X2000

X2000 Future Deliveries Vision

- On 4-6 year centers, revolutionize the *remote sensing, full spacecraft* capability.
- In between these deliveries, enable *new systems* for new exploration approaches and provide a path for progress towards the next revolution.

sharpening capabilities (orbiters, flybys, probe carriers, landers, ...),

broadening the exploration toolset (penetrators, aerobots, subsurface systems, ...)



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Deep Space Systems Technology Program

Introduction to X2000

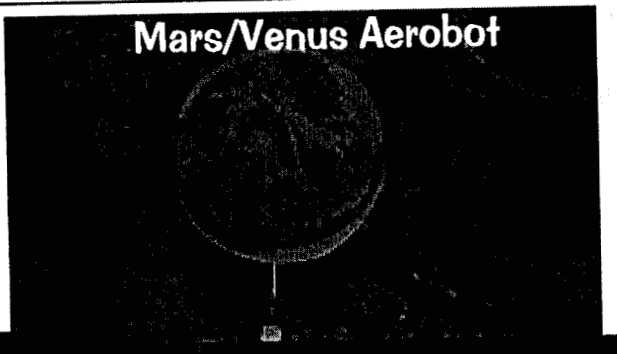
JPL

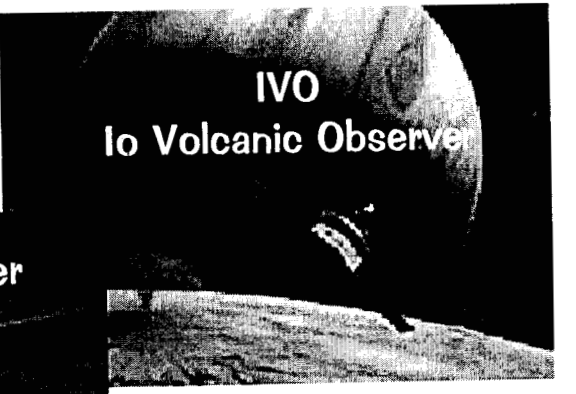
DSST X2000

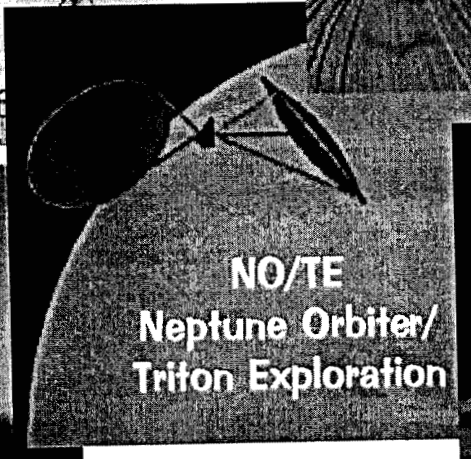
Future Deliveries: Develop Technology for Missions in the Code S Strategic Plan

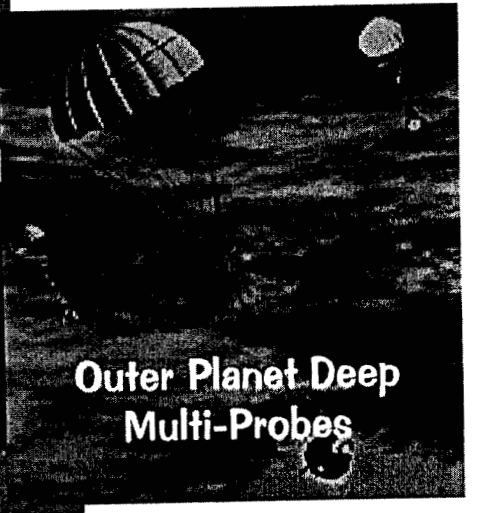
Need advanced capabilities in many diverse systems: Orbiters, landers, probes, rovers, penetrators, aerobots, aircraft, sub-surface, submarine, ...?

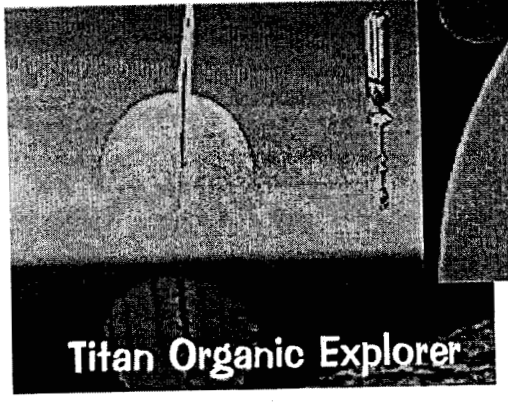
Broad Benefit to: Discovery, Mars, SMEX, Commercial, DoD, ...?

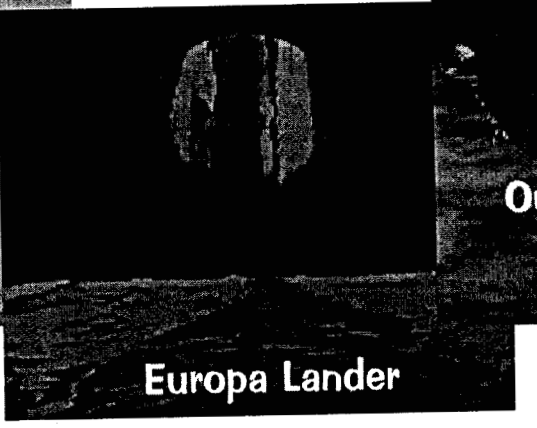












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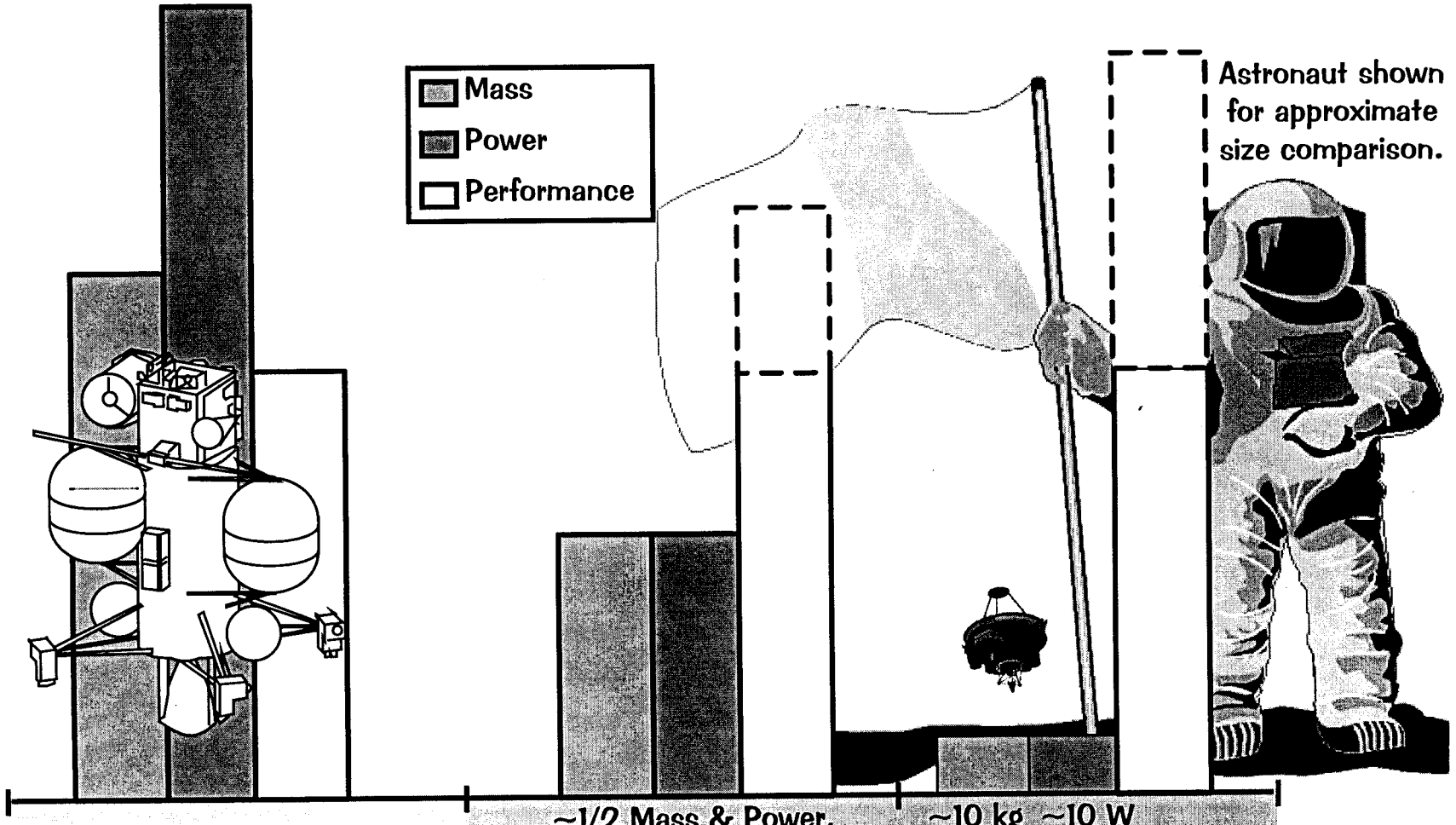
Deep Space Systems Technology Program

Introduction to X2000

X2000 – Trend in Future Delivery Metrics



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New Material:

No technology

Deep Space Systems Technology Program

Introduction to X2000
Focus of Second Delivery

DSST X2000

- Worked with NASA community to select technology foci for Second Delivery
  - NASA Office of Space Science (Code S) – primary sponsor for program
  - NASA Offices of Earth Science (Code Y) and Space Flight (Code M)
  - Goddard Space Flight Center
  - JPL Future Mission Programs
  - JPL Technology Programs
- Decision was made jointly by NASA and JPL according to these selection criteria:
  - Contains portfolio of advanced technology ("wow factor")
  - Contributes to a large set of future missions
  - Cost profile fits within available budget
  - Development provides continuity to Third Delivery
- Second Delivery will focus on enabling microspacecraft in the 10-50 kg range. Particular technology foci will include:
  - Integrated avionics
  - Optical communications
  - Communication relays
  - Mini propulsion

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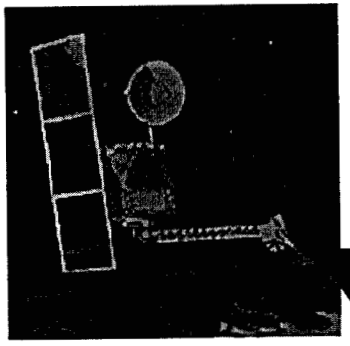
Deep Space Systems Technology Program

Introduction to X2000

Some Possible Second Delivery Beneficiaries

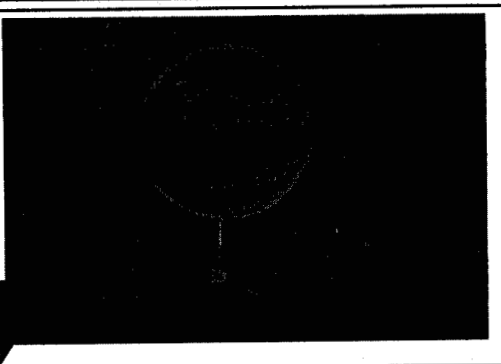
JPL

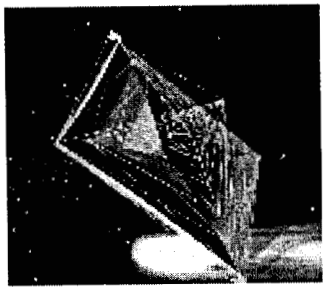
DSST X2000



Mars Micro-Mission Carriers or Science Platforms

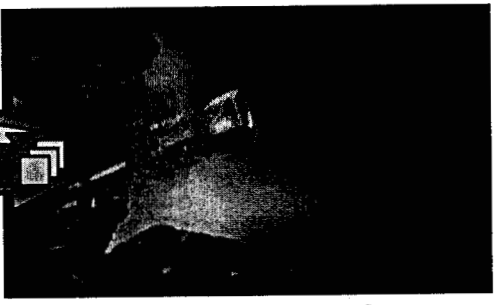
Aerobots, rovers, and other small platforms



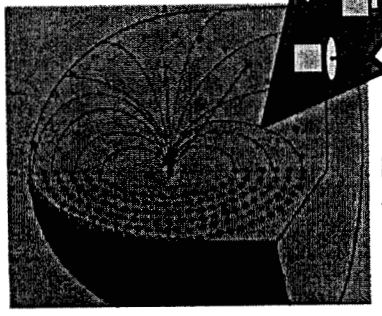


Interstellar Precursor (Solar Sail Demos)

Delivery 2 System

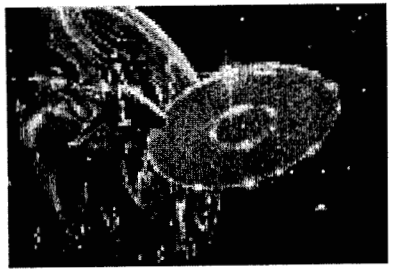


Daughter spacecraft or other separable payloads



Networks of tiny spacecraft

Gossamer spacecraft; large lightweight structures with distributed functions in small nodes.



= Integrated Avionics

/ = Deep Space/Relay Communications

= Mini Propulsion

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New Material:

No technology

Deep Space Systems Technology Program

Introduction to X2000

Old Versus New - The Benefits of X2000

DSST X2000

Old way: *5 Traditional (Independent) Missions	New way: X2000 and 5+ Customer Missions
5+ independent technology development efforts	x 5 One central technology development with innovative system engineering fits many missions
$ $ $ $ $ 5+ sets of acquisition costs	$ One set of acquisition costs
Relationship with industry - fresh start with every project	Contracts Long term partnering relationships – foster investment and better understanding
Launch - 3 years Early commitments required to develop each Spacecraft	Launch - 1 year "Continuous" production over 5+ missions allows later commitments/more flexibility
Requires dedicated JPL/Industry staff for each project	Unique up-front work by JPL and industry team; Industry team takes over for subsequent production (tech transfer)
5+ Development teams to train	X2000 Team supports all missions
5+ Sets of processes and tools	Single tool set serves all
? ? ? ? ? Each Project starts over with risk	? Much of spacecraft risk shouldered once by X2000
Each project will be risk averse toward innovative science	*Low risk spacecraft* allows missions to be more innovative (take more risk) with science

Easter